Three Essays on the Economic Role of Distance, Transport and Communication

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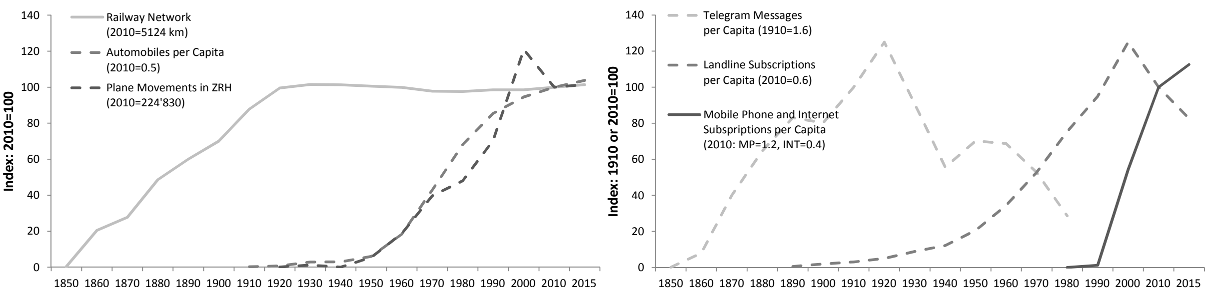
Contents

1 Introduction

Like many other countries, Switzerland has benefited from three waves of epoch-making innovations in transport and communication technologies (see Figure 1.1). It started in the 1850s with the triumphant success of the railway and the telegraph. Being a small export-oriented market with few natural resources, efficiency gains in the transport sector were of particular importance for Switzerland. Railway made overland transport not only faster but also more reliable, reducing costs by a factor of almost ten. The 20th century was characterised by the rise of cars, planes, landline telephones, and broadcasting. These innovations have been mainly introduced in the early 1900s, yet they were not accessible to the masses before the second half of the century. At the turn of the millennium, a third wave of communication technologies conquered Switzerland, namely mobile phones and the internet. While only a small minority used these technologies around 1995, both mobile phones and internet achieved a very high market penetration by 2010.



(a) Transport Technologies (b) Communication Technologies

Figure 1.1: Market Penetration of Transport and Communication Technologies, 1850–2015. *Data Sources:* FSO, BAKOM, HSSO.

In principal, transport and communication infrastructure serve the same purpose: overcoming distance.[1] The financial costs and time required to move goods, people, and information crucially shapes the location decision of companies and people. Without a doubt, the continuous technological progress drove down the costs of transport and communication. For instance, Swiss ICT-providers have increasingly shifted to flat-rate schemes for domestic telephone services and

[1]It is interesting to note that in the 19th century, the movement of goods or people and the movement of information were seen as identical processes, both being described by the common noun "communication" (Carey, 2009, p. 12).

internet subscriptions, the later making international calls via Voice Over IP at practically no charge possible. Quickly melting distance premia in the transport and communication sector gave rise to the "Death of Distance"-Hypothesis (Cairncross, 2001), arguing that frictions in economic exchange due to physical distance continuously loose importance. This thesis contributes to the debate on how transport and communication innovations have been affecting the spatial distribution of economic activity in general and the role of cities in particular.

Chapter 2, which is joint work with Stephan Kyburz, studies the impact of railway access on the spatial distribution of population and economic activity in the second half of the 19th century. The small-scale municipalities of Switzerland present a unique setup that allows to analyse the impact of the railway expansion at a level of geographic detail not seen in other studies. We compile a data set that combines geo-referenced railway network information and various proxies for regional economic development, including population growth rates for more than 2800 municipalities, as well as data on sectoral work shares and the body height of conscripts in 178 districts.

The analysis takes into account that railway companies might have specifically targeted fast developing towns and villages. Linking topographic features and railway construction expenses, we simulate hypothetical railway lines that connect the major towns at the least cost possible, and then use these lines to instrument actual railway access. This so-called inconsequential units IV approach and the careful analysis of pre-railway data allow us to infer whether transportation infrastructure indeed promoted growth or just followed favourable regional developments.

The main results show that the growth of urban centres quickly accelerated after the adoption of the railway technology, while the impact was considerably smaller in rural municipalities along the rail tracks. Moreover, the positive effect of railway in rural areas was markedly localised, as municipalities situated more than 2 km from the railway network experienced a slowdown in growth. The negative effect of railway was largest for municipalities at 6 to 8 km distance from the railway tracks and reversed back to zero for places at least 20 km away. This pattern was primarily driven by the migration balance, as fertility rates were hardly impacted. Apparently, people living in an intermediary distance to the railway dislocated to places right at the railway tracks.

Chapters 3 and 4 deal with the question of how information disseminates in the modern world. These two chapters build on the distinction between codifiable and uncodifiable information (see Storper and Venables, 2004, p. 353–354): *Codifiable information* has a stable clearly defined meaning. Such information is cheap and easily transferable, because its underlying symbol system can be widely disseminated through communication infrastructure. In contrast, *uncodifiable information* is only loosely related to the symbol system in which it is expressed, such that a successful transmission often requires face-to-face contact. Relative to electronically mediated exchange, direct social contact offers the capacity for instantaneous interruptions, feedback, and body language cues. These advantages are of particular relevance in the context of social learning and the exchange of messages that require some degree of trust or involve emotions.

Chapter 3 provides an implicit test of the hypothesis that modern communication technologies make a frictionless dissemination of *codifiable information* possible. It documents how statements by European policy-makers affected the price of securities issued by five peripheral European countries, namely Greece, Ireland, Italy, Portugal, and Spain.

The timing and content of statements are determined based on a comprehensive collection of newswire reports issued between January 2009 and August 2011. Using content-analysis techniques, each statement is either recorded as signal of strong determination in the rescue of indebted countries, or as signal indicating limited commitment to support the heavily indebted peripheral countries and protect their creditors. This approach yields a very rich communication measure including 600 statements by about 70 different policy-makers.

The examination of daily financial market fluctuations reveals that statements by European policy-makers impacted CDS and bond yield spreads on the same day. Without an immediate dissemination of the statements via radio, television and internet such quick reactions of globally traded assets would not be observable. The strongest market reactions occurred on days with statements by representatives of Germany, France and the EU institutions in Brussels. Regarding communication by ECB officials, the statistical analysis shows that alongside the source of a message, its content played an important role as well. Whereas no coherent effects on CDS and bond yield spreads are found for ECB statements on matters within the political domain, there is some evidence that communication on government bond purchases and the collateral framework moved financial markets.

Chapter 4, which is joint work with Maximilian von Ehrlich, analyses whether the dense concentration of cities provide a favourable environment for social interactions, and therefore better conditions for social learning and the flow of *uncodifiable information* in general. This idea lies at the core of one of the classic agglomeration forces described by Alfred Marshall (1890), who argues that the dense concentration in cities facilitates the flow of knowledge, since social interactions diminish over space. Despite being a core idea in urban economics, the underlying mechanisms have hardly been studied so far, or in the words of Edward Glaeser (2000, 104): "Urban economics needs to increase its focus on non-market interactions because they are central to an understanding of causes and effects of cities."

The analysis builds on anonymised mobile phone calls between June 2015 and May 2016, covering 7 million devices that transmitted 15 million calls and text messages per day. Along with the anonymised CDRs, the operator also provided monthly updated customer information including billing address, language of correspondence, age, and gender. Based on this rich dataset and concepts from the network literature, three main questions are investigated. First, how does geographical distance impact social interactions? Second, what is the relation between population density and the size of an individual's social network? Third, does population density affect the quality / efficiency of social interactions in terms of matching quality, clustering and network perimeter?

The identification strategy employed in this study rests on two complementary approaches. The first approach aims to identify factors that predict the likelihood of individuals i and j

forming a link. The second approach estimates the effect of local characteristics on individual-level network measures. Sorting of individuals with specific characteristics can affect the results of both types of regression analyses. As the data encompasses the full social network for one year, changes in the address of mobile phone customers can be exploited; this allows to isolate the role of systematic sorting and to obtain causal estimates of geography and population density on network formation and network topography.

The main results suggest that distance is highly detrimental to social interactions. Despite epoch-making progress in communication technologies, more than 60 percent of ties occur between individuals that reside within less than 10 km distance of each other. Contrary to the conventional view, this does not translate into larger networks in cities compared to the periphery. Density-related externalities rather arise in terms of network efficiency, namely better matching quality, lower clustering, and smaller distance costs. Evidently, modern communication technologies do not render cities obsolete. Our analysis has illustrated that they remain important as catalyst of valuable social exchange and, consequently, as potential engines of growth.

2 Fast Track to Growth? The Impact of Railway Access on Regional Economic Development in 19th Century Switzerland*

2.1 Introduction

The rapid advance of railways is widely seen as a major driving force of economic development in the 19th century. It made overland transport at competitive rates possible, which facilitated the integration of formerly isolated areas into the regional and global economy. As this market widening enabled increased regional specialisation and gains from trade, it is argued that railway substantially accelerated aggregate economic growth.[1]

Then as now, investments in transportation infrastructure have repeatedly been endorsed by policy makers as a means to promote regional economic development. Economic considerations, both from a *national growth* and *regional development* point of view, also dominated the political debate on the foundation of a national railway network in 19th century Switzerland. Being a small export-oriented market with few natural resources, Switzerland was particularly dependent on fast and reliable means of transport. For this reason the federal government emphasized that a well designed railway network was critical to the country's welfare.[2] In 1852 the provision of railway infrastructure was mandated to private companies. From a regional economic growth perspective this raised concerns that domestic disparities would widen, if underdeveloped and thinly populated areas were neglected by railway entrepreneurs.[3]

[1]Based on the concept of social savings, first proposed by Fogel (1962, 1964), the impact of railway infrastructure on aggregate output has been calculated to range between 5% and 10% for the US, and between 1% and 11% for European countries (Leunig, 2010). In a recent study, Donaldson and Hornbeck (forthcoming) show that extensions to internal waterways and roads would have mitigated at most 20% of the losses from removing railways in the US, refuting the famous argument by Fogel (1964) that railways could have been easily substituted by other available means of transport.

[2]Original quote from the federal council's statement delivered to the national assembly on 7th April 1851 [BBl 1851, Vol. 1(19):352]: "Was wir [...] vor Allem als Hauptzweck eines schweizerischen Eisenbahnnetzes betrachten, besteht in Erleichterung des Verkehrs im Innern. Auf dem europäischen Kontinent ist kaum ein Land wie die Schweiz, das so wenig im Stande ist, seine Bedürfnisse auf eigenem Boden zu erzeugen, das daher in so hohem Grade interessiert ist, dass es seine Konsumgegenstände, seine Rohprodukte wohlfeil beziehen und seine Fabrikate wohlfeil ausführen kann. Kaum ein Land [...] wo die Schnelligkeit des Personenverkehrs und der Warensendungen von so hohem Werthe ist, wo das Englische Sprichwort 'Zeit ist Geld' in gleichem Masse seine praktische Anwendung findet."

[3]Opponents of a private provision fiercely warned that railway companies will cherry-pick the most profitable

*This chapter is joint work with Stephan Kyburz.

How early railway access impacted regional growth in Switzerland has not yet been studied quantitatively. We compile a data set that combines geo-referenced railway network information and various proxies for regional economic development, including population growth rates for more than 2 800 municipalities as well as data on sectoral work shares and the body height of conscripts in 178 districts. The small-scale municipalities of Switzerland present a unique setup, that allows us to analyse the impact of railway at a level of detail not seen in other studies. Particular attention is paid to potential selection effects induced through strategic routing: An inconsequential units IV approach and placebo tests based on data from the pre-railway era allow us to infer whether transportation infrastructure indeed promoted growth or just followed favourable regional developments.

The empirical evaluation of how transport infrastructure affects economic activity has recently attracted increased attention (see Redding and Turner, 2014).[4] Fishlow (1965) was one of the first economic historians who systematically analysed the direction of causation in this context. Based on his study of 19th century USA, he concludes that railway construction seems to have followed demand rather than cause regional population growth. Combining GIS-tools and econometric methods, Atack et al. (2010) revisited Fishlow's analysis for counties in the American Midwest from 1850 to 1860. They find that railway access increased population density by about 3 percentage points within the decade studied. The impact of railway access in Switzerland was of comparable magnitude, as our preferred models yield an average railway induced growth effect of 0.4 percentage points per year. While Atack et al. (2010) explore the impact of railway on population growth in a mostly rural environment similar to our case, US counties are rather coarse units of analysis in comparison to Swiss municipalities. Exploiting the fine granular level of our data, we cannot only investigate the direct impact of railway access; we can also examine local displacement effects of railway infrastructure as well as effect heterogeneity along various dimensions.[5] Our results show a non-monotonic functional relation between distance to the railway network and population growth: The positive effect of railway was markedly localised, as municipalities situated more than 2 km from the railway network experienced a slowdown in growth. The negative effect of railway was largest for municipalities at 6 to 8 km distance from the railway tracks and reversed back to zero for places at least 20 km away.

A well-researched consequence of expanding railway infrastructure is the faster growth of cities, as documented by studies for Prussia (Hornung, 2015), Sweden (Berger and Enflo, forthcoming), and Africa (Jedwabi and Moradi, 2016). Switzerland also experienced rapid urba-

lines, as the majority report by the parliamentary railway commission in 1852 illustrates [BBl 1852, Vol. 2(27): 49-127].

[4]In the main text, we only discuss studies on railways built in the 19th century. Comparable questions were also studied for highway infrastructure built in the 20th century, for instance by Duranton and Turner (2012) or Faber (2014). For Switzerland, Dessemontet (2011) documents in detail how the spatial pattern transformed from a very strong centre-periphery specialisation in 1939 to a much more sprawled distribution in 2000, with road-accessibility being an important determinant of employment density. In addition, Müller, Steinmeier and Küchler (2010) show that the rate of urban growth increases with proximity to a motorway exit.

[5]Another spatially detailed analysis was conducted by Koopmans, Rietveld and Huijg (2012) who study accessibility and population growth in Dutch municipalities. Whether their results have a causal interpretation is questionable, however, as they neither provide placebo tests nor exploit exogenous variation.

nisation during the early railway era, yet the vast majority of people lived in markedly small rural municipalities throughout the 19th century. Hence, our analysis naturally complements studies on railway and city growth, bringing the demographic developments in peripheral areas into focus. Our estimated effect of railway access on population growth is considerably smaller than the impact reported for cities, which typically ranges between 1 and 2 percentage points per year. This substantiates the notion that railway access primarily promoted growth in cities and regional centres, while the impact was considerably smaller in rural municipalities along the rail tracks. Nonetheless, our findings do not lend support to the home market effect hypothesis as in Krugman (1980), since we find little evidence for negative growth effects of transportation infrastructure, even in the least populous communities.

Population growth often serves as a proxy for regional development, because comprehensive income and production statistics for the 19th century are scarce. On theoretical grounds, freedom of movement facilitates migration flows that equalise real wages across space, implying migration from uncompetitive to competitive areas (e.g. Redding and Sturm, 2008). Indeed, our analysis of birth, death, and migration statistics shows that railway access primarily had an impact on population growth via the local migration balance. Reduced trading costs are considered to be the main mechanism that links railway – and transportation infrastructure in general – to competitive advantages and economic activity. Donaldson (forthcoming) reports conclusive evidence for this channel; based on data for India between 1853 to 1930, he shows that the advance of railways substantially lowered trade costs and promoted intra-Indian trade flows. Improved trading conditions due to railway access caused a significant increase in agricultural income, as is documented for the US (Donaldson and Hornbeck, forthcoming), India (Donaldson, forthcoming), and Ghana (Jedwabi and Moradi, 2016). Other studies provide evidence that obtaining railway access accelerated industrialisation, since it promoted capital investments in manufacturing companies (Tang, 2014) and increased the average firm size (Atack, Haines and Margo, 2008; Hornung, 2015). These findings for the agricultural and industrial sector raise the question of what the net effect was of railway on structural change. We show that districts with average railway access experienced an additional 9 percentage point shift in labour shares from the agricultural to the manufacturing sector within 40 years compared to unconnected districts. This evidently suggests that improved railway infrastructure was an important driver of industrialisation in Switzerland. Considering that the (sparsely available) income records document higher wages in the manufacturing than in agriculture (see Brugger, 1978; Gruner, 1987), railway-induced industrialisation may have been a key pulling factor shaping migration patterns. Although we lack the data to investigate this claim in detail, an analysis of body height records provides evidence that railway indeed had a positive net effect on the population's (biological) well-being, most likely through improvements in nutrition and labour conditions.

The next section describes the historical setting. Section 3 introduces the data used in the empirical analysis. Section 4 explains the empirical strategy to identify the causal effect of railway access on regional development. Section 5 discusses the results for the municipality and district level. Section 6 concludes.

2.2 Historical Background

Although Switzerland was one of Europe's most industrialised countries in the early 19th century, railway technology caught up relatively late.[6] Since 1836 entrepreneurs in Zurich sought to connect Switzerland's largest city to the foreign railway network at the German border in Koblenz and the French border in Basel, but since they failed to raise enough funds their endeavour stopped halfway in Baden. The first 23 km of railway tracks in Switzerland, which are known as "Spanisch-Brötli-Bahn", were opened in 1847, at a time when Great Britain (9 800 km), Germany (5 800 km), France (2 900 km), and the US (13 500 km) had already built several thousand kilometres of railway.[7]

When the Swiss federal state was founded in 1848, the formation of a national railway network soon became one of the main priorities on the political agenda. Alfred Escher, president of the national council, forcefully warned his fellow members of parliament in 1849 that Switzerland would run the risk of becoming isolated within Europe if it failed to build a railway network quickly.[8] In 1850, the government commissioned two English engineers, Robert Stephenson and Henry Swinburne, to provide a technical expertise for the construction of a national railway system. After fierce debates and a close vote, the plan submitted by the English engineers for a state-run railway network was rejected by the national assembly. The Railway Act of 1852 authorised cantonal administrations to grant concessions to private companies, which were supposed to build and run Switzerland's railway network without public funding (Weissenbach, 1913, 6). This new legal framework along with the introduction of a single currency and the elimination of internal tariffs in 1848 evidently reassured previously reluctant investors, and within a decade private railway companies connected Switzerland's major cities north of the Alps. By the end of the century Switzerland had one of the world's densest railway networks with a total length of around 3 700 km (see Table 2.1).

Switzerland is a land-locked country with no navigable rivers except for the Rhine in the border town of Basel. Before railway became available, carts were the main means of transportation complemented by inland navigation on lakes.[9] It has been estimated that railway reduced

[6]Bairoch (1965) compares nine European countries, the US, and Japan in terms of industrial development between 1800 and 1900, with Switzerland coming in fourth or fifth place throughout the 19th century.

[7]Humair (2008) cites the fragmented system of tariffs, currencies and jurisdictions of the pre-modern Swiss confederation as key institutional barriers that inhibited adequate funding by (foreign) investors. Furthermore, he points to the opposition of various social and economic stakeholders, as well as disputes about route planning that delayed railway investments. The international rail network statistics represent total track length in 1850 and are taken from Sperber (2009, 10) and Adams (1895, 6).

[8]Original quote from Alfred Escher's speech delivered in the national assembly on 12th November 1849 [BBl 1849, Vol. 3(6):161]: "Es tauchen Pläne auf, gemäss denen die [europäischen] Bahnen um die Schweiz herumgeführt werden sollen. Der Schweiz droht somit die Gefahr, gänzlich umgangen zu werden und in Folge dessen in der Zukunft das traurige Bild einer europäischen Einsiedelei darbieten zu müssen."

[9]The relative importance of inland navigation prior to 1848 has not yet been conclusively determined, as detailed transport statistics are not available for that period. The historical research available suggests that inland navigation was a regionally important – but *secondary* – complement to overland transport. First, Switzerland only had 25 steamboats in 1850 (Schiedt, 2009, 172). Second, costs for transshipping were significant, which limited potential savings on the relatively short portage routes on lakes (Schiedt, 2009, 173). Third, estimates by Frey (2010) suggest that the accessibility of Swiss municipalities in 1850 was almost entirely determined by roads (93%-100%), and hardly influenced by inland navigation (0%-7%). Fourth, Schiedt (2007) documents the broad

Table 2.1: Railway Density in Selected Countries, 1900

	Railway Network in km	
	per 10tsd Inhabitants	per 100 Sq-Km
Germany	9.7	9.3
Austria-Hungary	8.2	5.4
France	10.9	7.9
Italy	5.0	5.5
Great Britain	8.6	11.0
USA	42.2	3.8
Switzerland	12.4	9.1
Lowland (excluding alpine area)[1]	11.6	18.4

1: Railway lines and population of districts with a mean elevation below 1 000 m.a.s.l., representing the area of our robustness analysis. *Source:* Geering and Hotz (1903, 105-106).

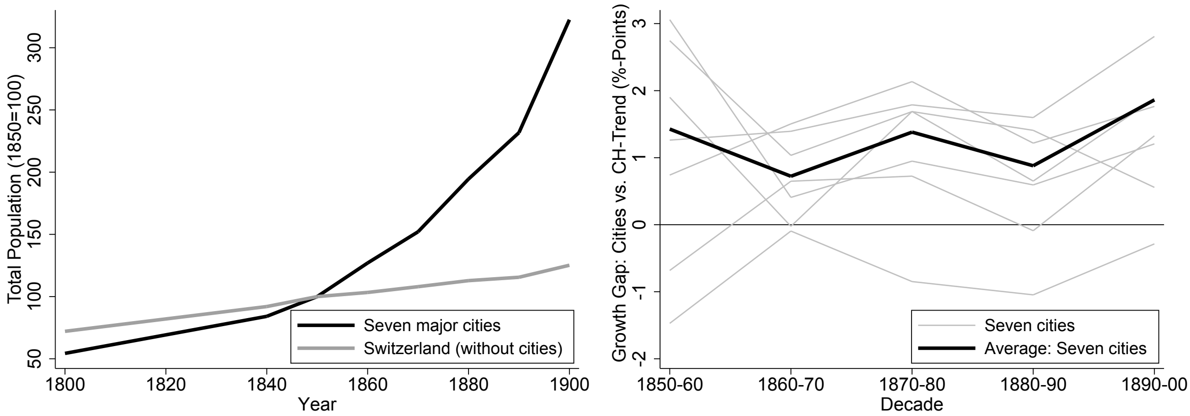
land transport costs by a factor of eight (Donaldson, forthcoming), which stimulated two major developments in Switzerland: First, the agricultural sector started shifting production from grain to dairy products. While the production of milk increased by more than 70% until the end of the century, the production of grain decreased by 40%, a drop that was compensated by the quadrupling of grain imports (Frey and Vogel, 1997, chapter 8). Second, railway triggered large quantities of coal imports from Germany and France, which increased from 1 360 tons in 1851 to 16 000 tons ten years later, and more than 200 000 tons at the end of the century, representing 15% to 20% of the freight transported by rail between 1850 and 1900. Coal promoted an improved mechanisation of the Swiss industry, and cleared the way for energy-intensive sectors such as steel works, salterns, and cement production (Marek, 1991, chapter 6).

Besides lowering the transportation costs of cargo, railway substantially shortened travel-times. Frey (2006) illustrates on the basis of detailed stagecoach and train schedules that the time required to visit all cantonal capitals was halved between 1850 and 1870. By the end of the century, travel-times were even reduced by 80% compared to the pre-railway period. Despite these substantial improvements in accessibility, Frey and Schiedt (2005, 57) argue that railway contributed little to the public's mobility during the first 40 years, as it was unaffordable for the vast majority.[10] In 1880, Swiss railway companies only carried 25 million passengers, which corresponds to an average of nine train journeys per person per year. A gradual decline in fares during the 1890s and rising incomes made train travel more widespread, with yearly passenger numbers rapidly increasing to 63 million in 1900 and 110 million in 1910.[11] For most of the 19th century, however, rail journeys remained a privilege for the wealthy and commuting by train was rather insignificant.

modernisation of Switzerland's road infrastructure from 1740 to 1780 (around 1 000 km) and from 1830 to 1840 (around 6 000 km). The fact that these investments accounted for up to 40% of cantonal finances underlines the importance attributed to roads by policy-makers in pre-modern Switzerland.

[10] A look at fares and wages in the 1880s illustrates this point: An average worker, who earned about 0.30 CHF per hour, had to pay 0.90 to 1.40 CHF for a return-ticket on a 10 km railway route (NOB, 1883).

[11] Passenger statistics were obtained from the *Schweizerische Eisenbahnstatistik* (SPE, 1900), which is partly accessible online at `http://www.bahndaten.ch/` (last access: 01.02.2016).



(a) Population Development, 1800-1900 (Index: 1850=100).

(b) Difference in Difference: National Population Growth Rate p.A. vs. City Growth Rates p.A.

Figure 2.1: Urbanisation and Railway in Switzerland. *Source:* Own calculations based on the *HSSO* database, `www.fsw.uzh.ch/histstat/`
Notes: The sample of cities includes Zurich, Geneva, Bern, Basel, Winterthur, Thun, and Biel. Cities were selected only if their population statistics for 1800 and 1837 reflect the territorial borders of the 1850–1900 sample. Graph (b) shows difference-in-difference annual growth rates: The differences between national and city growth rates from 1837 to 1850 were subtracted from the annual growth rate differences between 1850 to 1900 .

The advent of railway took place in a period characterised by strong growth: Swiss GDP estimates available for the period after 1850 reveal that real output grew by approximately 250% within 50 years, while the population increased from 1 665 000 inhabitants in 1800 to 2 393 000 in 1850, and 3 315 000 by the end of the 19th century. This growth was not uniformly distributed across the country, however, as Switzerland witnessed substantial domestic migration typically from peripheral regions to the fast growing urban centres (e.g. Rey, 2003). The acceleration of urban growth in Switzerland coincides with the construction of the earliest railway lines. To illustrate this point, Figure 2.1 part (a) plots population statistics (1850=100) for a sample of seven cities with comparable population data for 1800 and 1836/37. While cities grew at a similar rate to other municipalities prior to railway construction (i.e. between 1800 and 1847), the picture changed completely in the second half of the 19th century. Urban population started increasing tremendously while the rest of the country kept growing at a relatively constant rate. Part (b) of Figure 2.1 presents a simple difference-in-differences analysis of the annual population growth rate of the seven cities compared to the national population growth rate using periods before and after the introduction of railway technology. Except for Thun, the growth rates of the cities increased by 0.5 to 3 percentage points relative to the national trend after the railway network was established. Of course this simple analysis cannot establish a causal relation, since early railway construction coincides with improved market integration following the birth of the modern federal state in 1848. Nonetheless, it reveals a suggestive pattern that fits well with recent findings on urbanisation and railway access in other countries.[12]

Although urban centres experienced rapid growth, Switzerland remained a rurally dominated

[12]For instance, Hornung (2015) shows that railway access accelerated population growth in Prussian cities by an additional 1 to 2 percentage points per year, which is quantitatively similar to the increase in Switzerland's urban growth rates after 1850.

country throughout the 19th century. In 1850, less than 10% of Switzerland's population lived in towns of more than 10 000 inhabitants, a ratio that remained decidedly below the 50% mark until the end of the century. In the following, we primarily analyse how demographic dynamics in Switzerland's rural areas were affected by railway access.

2.3 Data

We track the expansion of Switzerland's railway network using data from the "GIS Dufour" project, which developed a digitial map of historic roads, railway, and waterway lines based on the first national map commissioned by Henri Dufour in 1850 (source: Egli et al., 2005). In addition to mapping traffic routes, the GIS Dufour project also collected information on their opening and closing dates from various historical sources. Based on this rich data set, we define a binary indicator, referred to as *railway access*, that takes the value 1 if one or more railway lines cross over the territory of a municipality.[13] Accordingly, we call municipalities "treated" after they received their first railway access, and "untreated" if no railway line passed through. Column 5 in Table 2.2 shows the percentage of treated municipalities for each decade and column 6 reports the population share that was connected to the railway.

Municipalities are the lowest administrative unit in Switzerland, with 1 to 40 municipalities forming a district, and 1 to 30 districts forming a canton, the equivalent of a US state. In order to evaluate the impact of railways at the district level, we calculate the population weighted share of municipalities that had direct access to the railway network for each district and decade.

Our main outcome of interest is annual population growth. Population statistics are taken from the census ("Eidgenössische Volkszählung") which has been conducted by the Swiss Statistical Office (and its precursor) since 1850.[14] The national census has always surveyed the population on the municipality level in intervals of 10 years, with the exception of the 1890-wave, which was collected in 1888. We infer the population for 1890 by performing an extrapolation of growth rates in the adjacent periods, i.e. 1880 to 1888 and 1888 to 1900, respectively.[15] In order to account for territorial reorganisations, we use the municipality classification for 2000 and clean population figures based on the data set's documentation on territorial mergers and divisions.[16] For the cantons of Zurich, Bern, Aargau and Solothurn, we complement the census data with population statistics from the "Helvetische Zählung" conducted around 1800 and the "Tagsatzung" in 1837. These early population counts are currently being harmonised with the post-1850 census data in an ongoing project by Schuler and Schluchter (in progress). In what

[13]We use municipal boundaries from official administrative maps of Switzerland valid from January 2000. This ensures that the spatial administrative division used to determine a municipality's railway access is congruent with the classification employed in the census data.

[14]Detailed information on the data set, which can be downloaded from `www.bfs.admin.ch`, is provided in Schuler, Ullmann and Haug (2002).

[15]Mathematically, we calculated the population count (POP_{90}) of 1890 as follows:
$PGR_{80,88} = (\frac{POP_{88}}{POP_{80}})^{1/8}$; $PGR_{88,00} = (\frac{POP_{00}}{POP_{88}})^{1/12}$; $POP_{90} = \frac{1}{2}POP_{88} \cdot (PGR_{80,88})^2 + \frac{1}{2}POP_{88} \cdot (PGR_{88,00})^2$.

[16]For instance, the municipality of Turgi (ID=4042) with a population of 645 in 1888, was part of the municipality Gebenstorf (ID=4029) until 1883. When calculating annual growth rates between 1880 and 1890 for Gebenstorf, we subtracted 645 from its population in 1880.

Table 2.2: Descriptive Statistics: Population and Railway Access in Swiss Municipalities

	Swiss Pop. (in mio.)	Municipalities: Average Population		Rail Access: %-Share of	
		All	With Rail Access	Municipalities	Population
1850	2.39	840	8603	0.3	3.2
1860	2.51	877	2049	12.9	30.0
1870	2.66	927	2006	17.4	37.5
1880	2.83	986	1817	29.3	53.9
1890	2.92	1013	1797	35.1	62.4
1900	3.32	1150	2067	39.0	70.3

Source: Own calculations based on Swiss census data and GIS-Dufour data.

follows, we refer to this subset of municipalities, representing around 900 of the 2700 municipalities, as the *pre-railway sample* or *pre-treatment sample* (see Figure 2.3). District population figures between 1850 and 1900 are derived by aggregating up municipality statistics, and are then complemented with district-level data for 1800 collected by Schluchter (1988). We construct our main dependent variable, the annual population growth rate for each municipality and each district based on the population figures for 1800, 1837 (municipalities only), and 1850 to 1900.[17]

A concern may be that population changes caused by railway-related *construction work* is falsely attributed to improvements in a municipality's or district's accessibility. In order to address such concerns, we resort to Rey (2003, 147–149) who compiled a list of Swiss municipalities and districts that experienced extraordinary demographic volatility due to railway construction work (mainly tunnelling). These observations are removed from our sample in all steps of the analysis that evaluate the affected time period.[18]

The population and railway access data is complemented with district statistics on surpluses of births over deaths so that migration balances can be calculated (source: census since 1870), as well as sectoral work shares (source: census since 1860) and the body height of conscripts (source: Staub, 2010) which we interpret as complementary proxies for regional development. In order to merge the data sets reliably, we define a common district identifier and compare the population figures as reported in the various sources. Differences in population counts are retraced using the documentation on territorial reorganisations from the Swiss Statistical Office. Whenever applicable, district population figures are equalised between the data sources, for instance by changing the assignment of municipalities to districts. Districts where the revised population statistics differ by more than 2% are excluded from the statistical analysis.[19]

[17] Annual population growth is computed as follows: $APG^t = 100 \cdot (ln(POP_{t1}) - ln(POP_{t0}))/(t_1 - t_0)$.

[18] In this respect it is important to note that we evaluate the impact of railway access on *population growth rates* in the short- and long-term: While railway construction work may have had a confounding effect on short-term population growth rates, it is unlikely that long-term growth trends were affected by the inflow and outflow of construction workers.

[19] Table A.3 in the appendix provides a complete list of districts that are included in and excluded from the analysis, respectively.

2.4 Empirical Strategy: Instrumental Variable Approach

Railway access is not randomly assigned to municipalities, but may be correlated with numerous observable and unobservable characteristics such as population size, growth potential, economic structure, or the availability of cheap land. Since Switzerland's main railway infrastructure was built and run by private entrepreneurs until 1902, concerns related to targeted and selective routing cannot be ignored. Although a number of control variables are available, cross-sectional OLS regression may not be sufficient to account for these endogeneity issues. A priori, it is unclear whether an upward or downward bias dominates, thus making it difficult to interpret plain regression estimates.

We address these concerns by adopting an *inconsequential units IV approach* first proposed by Banerjee, Duflo and Qian (2004; 2012) and later used in several studies on transport infrastructure, including Hornung (2015) and Atack et al. (2010). The underlying idea is compelling: In the early stages of transport infrastructure developments, major cities – hereinafter "main nodes" – are typically connected first. If railway companies built their routes such that two main nodes are connected as directly as possible, railway access would be randomly assigned to municipalities lying along these inter-node connections. It is likely, however, that railway companies deliberately take detours, for instance to connect municipalities with a high growth potential or to avoid expensive land acquisitions in dense areas. As these targeted detours induce selection effects, it is not sufficient to restrict the analysis to inter-node lines as they were actually built. Instrumental variables based on least-cost paths between nodes solve this issue. The IV approach bases inference on the randomly chosen subset of municipalities that received railway access because they lie on the most direct route between nodes, i.e. on a least-cost path.

2.4.1 Main Nodes

Main nodes are selected along two dimensions in this study, namely economic and transport strategic importance. As a first group, we chose the 20 most populous municipalities in 1850 that held the historical town status.[20] In medieval times, towns privileges included judicial liberties, coinage, the right to collect tariffs, and the right to hold markets, which we consider a good proxy for historically grown economic importance. These 20 nodes are supplemented by 23 locations listed as central traffic junctions in plans delivered to the federal government by Robert Stephenson and Henry Swinburne in 1850.[21] Since 10 municipalities are included in both sets, this yields 33 main nodes, that we believe were of primary economic or transport strategic importance, thus making them attractive to railway companies. These 33 municipalities are excluded from the sample in all steps of the statistical analysis, as they have gained access to the railway for reasons potentially endogenous to population growth.

Table 2.3 shows that 30 out of 33 municipalities selected as main nodes were connected

[20] Whether or not a municipality held the historical town status is determined based on Guyer (1960).

[21] Figure A.1 in the appendix displays the original plan outlined by the two English engineers, including the set of main nodes used in our analysis.

Table 2.3: Main Nodes

Municipality	**Population in 1850**	**RW Access**	**Municipality**	**Population in 1850**	**RW Access**
Among 20 Largest Towns & Listed as Node in 1850-Expertise					
Zurich	41585	1847	Luzern	10068	1859
Bern	29670	1857	Schaffhausen	8477	1857
Basel	27844	1844/54	Chur	6183	1858
Lausanne	17108	1856	Thun	6019	1859
Winterthur	13651	1855	Solothurn	5370	1857
Among 20 Largest Towns			Listed as Node in 1850-Expertise		
Geneva	37724	1858	Aarau	4657	1856
St. Gallen	17858	1856	Yverdon	3619	1855
Chaux-de-Fonds	12638	1857	Morges	3241	1855
Fribourg	9065	1862	Bellinzona	3209	1874
Le Locle	8514	1857	Baden	3159	1847
Neuchatel	7901	1859	Locarno	2944	1874
Altstaetten	6492	1858	Biasca	2035	1874
Lugano	5939	1874	Walenstadt	1868	1859
Biel	5609	1857	Rorschach	1751	1856
Vevey	5201	1861	Olten	1634	1856
			Brugg	1581	1856
			Lyss	1568	1864
			Romanshorn	1408	1855

Notes: The 20 largest towns are selected based on the Swiss census and an index of municipalities with historical town privilege from Guyer (1960). The list of nodes as suggested in the 1850-expertise by R. Stephenson and H. Swinburne is taken from Weissenbach (1913). Population figures are based on municipality border zoning from January 2000.

to the railway network by the early 1860s, which we consider to be the first wave of railway construction. The remaining four nodes, which are all located south of the Alps, received railway access in the 1870s, constituting the second wave of railway development in Switzerland.

2.4.2 Least-Cost Paths

Whether or not a least-cost path is drawn between two nodes is determined based on records of actual railway openings (source: Wägli, 1998; Weissenbach, 1913). Lines are selected only if the primary intention of the railway company was to connect two nodes, excluding routes that established inter-node connections gradually over long periods of time.[22] For the selected inter-node lines, we draw cost efficient routes on a 200 m x 200 m grid with the ArcGIS-tool "Least Cost Path" factoring in three cost parameters: distance, slope, and river crossings. In order to estimate the cost parameters, we extract information from the Swiss Traffic Atlas (source: NOB, 1883) on the total construction costs of 48 railway lines built by 1881, and combine it with information on mileage as well as slopes covered by the actual route of the tracks using a 25 m x 25 m height model for Switzerland (source: Swisstopo, 2004). A regression of total construction

[22]This excludes, for instance, the railway line connecting the nodes Bern and Luzern: Its first part was finished in 1864, connecting Bern with Langnau, while the section Langnau–Luzern opened 11 years later in 1875.

costs per kilometre on the routes' average slope yields average construction costs of 180 000 CHF per kilometre and an additional 15 000 CHF penalty per degree climbed. The costs of building bridges are determined based on the regression's residual for a 2 km track section that includes a 216 m long bridge over the river Rhine in Basel. We obtain costs of 800 000 CHF for the rail bridge in Basel, which we linearly scale down for smaller rivers based on federal water quantity statistics (source: Pfaundler and Schönenberger, 2013).

This procedure results in a least-cost path for every inter-node railway connection built in 19th century Switzerland, including information on the original route's opening date. Finally, we intersect the least-cost paths with municipal boundaries, giving us a measure, LCP^w, coded 1 if a municipality is traversed by a least-cost path during the construction wave w, and coded 0 if all the least-cost paths bypass outside the municipality in the given time span.

2.4.3 Estimation and Identifying Assumption

The data and instrumental variable, LCP^w_{ic}, described in the previous sections are used to estimate the effects of railway access, RA^w_{ic}, established during construction wave w, on annual population growth, APG^t_{ic}, in municipality i of canton c during decade t. The first and second stage regressions take the form

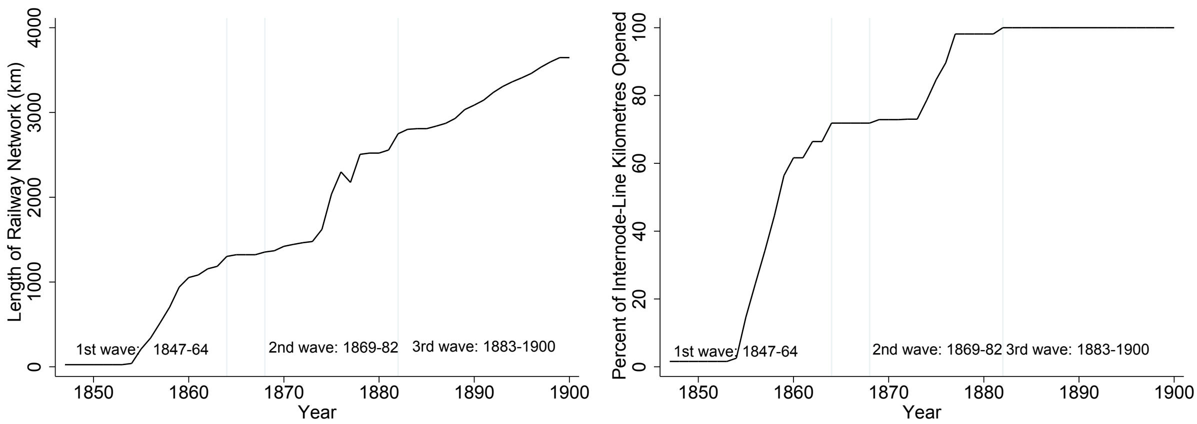
$$RA^w_{ic} = \alpha_1 + \beta_1 LCP^w_{ic} + \varphi_1 X^{1850}_{ic} + \kappa_{1c} + \epsilon_{ic}, \text{ and} \tag{2.1}$$

$$APG^t_{ic} = \alpha_2 + \beta_2 \widehat{RA}^w_{ic} + \varphi_2 X^{1850}_{ic} + \kappa_{2c} + \eta_{ic} \tag{2.2}$$

where κ_c denotes cantonal fixed effects, and X^{1850}_{ic} is a vector of municipality control variables described below.

A word on timing. The cross-sectional analysis exploits the fact that the construction of Switzerland's railway was carried out in three waves (see Figure 2.2): Between 1847 and 1864 the main trunk lines were established, including the east-west connection linking Geneva (westernmost city), Bern (capital), Zurich (largest city), and St. Gallen (easternmost city). During the second wave, 1869 to 1882, further inter-city lines were completed and the first north-south route through the Alps was opened. After 1882, the ramification advanced and mostly small branch lines were added. The focus of the analysis lies on the first wave, i.e. w=1847–1864, and the second wave, i.e. w=1869–1882. Equations (1) and (2) are estimated separately for both waves, and five decades of annual population growth available, i.e. t=1850–60; 1860–70; 1880–90; 1890–1900. When the second wave of railway constructions is analysed, all municipalities with access prior to 1869 are excluded from the sample.

Two assumptions are needed in order to allow for a causal interpretation of $\hat{\beta}_2$: First, the instrumental variable and the treatment have to be correlated (i.e. $\beta_1 \neq 0$), which can be tested formally based on the first stage correlation. Second, the exclusion restriction must hold, implying that the instrument needs to be as good as randomly assigned conditional on control



(a) Length of Swiss Railway Network (b) Share of Inter-Node Tracks Operating

Figure 2.2: Construction of the Swiss Railway Network: 1st Wave 1847–64, 2nd Wave 1869–82, 3rd Wave 1883–1900. *Source:* Own calculations based on GIS-Dufour data

variables, and may affect the outcome only through the first stage (e.g. Angrist and Pischke, 2009, 117). While our large and highly statistically significant estimates for β_1 verify the first assumption, the exclusion restriction could be violated if locations along the least-cost path are correlated with municipality characteristics due to history or geography. In order to justify the exclusion restrictions, we include a number of control variables, which are briefly motivated hereafter (further information on the controls are presented in the Appendix, 2.6).

By construction, municipalities nearby nodes are more likely to lie on a least-cost path than municipalities farther away. If proximity to a city or major traffic junction is correlated with population growth, the exclusion restriction would be violated. We therefore include the *log distances* of each municipality to its closest *town node* and to its closest *Stephenson-Swinburne node* as controls in our regressions.

The least-cost paths reflect direct routes between main nodes that avoid steep slopes and unnecessary river crossings. Location along these paths could be correlated with the economic structure of municipalities since they potentially coincide with historical trade routes that affected business prior to adoption of the railway technology. To account for this issue, we include a *road access* variable that measures whether a municipality is passed through by a major inter-cantonal road (source: GIS-Dufour, Egli et al., 2005). Before railway became available, these paved roads constituted the main inter-regional transport routes within Switzerland, and therefore should pick up possible confounding effects due to the potential correlation between historical trade routes and our instrument. Additionally, we include an indicator for *medieval town privileges* (source: Guyer, 1960), which were – amongst others – given to municipalities of trade strategic importance, and therefore may be correlated with both the likelihood of a municipality being crossed by a least-cost path and its population growth.

Naturally, our least-cost path algorithm tends to favour riversides, lake fronts, and low altitudes, as such terrain is often characterized by low gradients. A concern could be, that these places are also advantageous to economic development: Water turbines along rivers, for instance, were an important energy source in 19th century Switzerland, shipping on lakes was a regionally important complement to overland transport, while low altitudes pose favourable climatic conditions compared to higher elevations. Therefore, we include measures for *hydro power potential*, *adjacency to lakes*, and the *log of elevation* in our regressions.

A last set of controls is supposed to account for growth effects of *subsequent railway access*, and pre-determined population dynamics, namely *annual population growth prior to railway access*, the *log of population size in 1850*, as well as a municipality's *log area* in square kilometres.

Despite this broad set of control variables, it may still be possible that unobserved characteristics are correlated with both our instrument and the growth potential of municipalities, which would confound our estimate of β_2. We therefore follow an approach recently suggested in a similar setting by Hornung (2015), and complement our cross-sectional analysis with panel-models that take care of time-invariant unobserved heterogeneity by including municipality fixed effects, π_i. We regress the annual population growth rate of municipality i in decade t, APG_{ict}, on the instrumented dummy variable indicating railway access in the previous decade, RA_{ict-1}. The first and second stage IV panel-regressions are specified as

$$RA_{ict} = \pi_{3i} + \beta_3 LCP_{ict} + \lambda_{3t} + \lambda_{3t} \cdot \kappa_{3c} + \xi_{ict}, \text{ and} \tag{2.3}$$

$$APG_{ict} = \pi_{4i} + \beta_4 \widehat{RA}_{ict-1} + \lambda_{4t} + \lambda_{4t} \cdot \kappa_{4c} + \varepsilon_{ict} \tag{2.4}$$

where time fixed effects, λ_t, control for population growth cycles on the national level, and cantonal-time fixed effects, $\lambda_t \cdot \kappa_c$, account for cycles on the regional level.[23]

While the advantage of this approach is the elimination of potentially unobserved time-constant confounders, it washes out a lot of variance in the variables of interest and identifies the effect of railway access based on within-municipality variation only. Since the Swiss census was conducted with a periodicity of ten years, the timing of treatment and effect is rather imprecise in our setting: To eliminate concerns of reverse causality and because main lines were mostly built in the second half of the 1850s and 1870s, we use the first lag of railway access in our preferred panel specification, e.g. railway access between 1851 and 1860 affects population growth during the decade 1860 to 1870 and onwards. The following section reports and discusses the estimation results for both the cross-sectional and the panel-data analysis.

2.5 Results on Railway Access and Regional Development

Suggestive evidence for the impact of railway access on population growth is presented in Table 2.4, which compares the mean population growth rates for municipalities gaining railway access during the earliest wave of railway construction (1847–1864) to the growth rates of municipalities bypassed by these railway lines. While a two-sided T-test of differences in means (see column 4)

[23] Map A.4 in the appendix depicts the time-variation in our instrument.

suggests that population growth rates were not statistically different in the two groups during the pre-railway period, growth rates significantly diverged with the construction of the earliest railway lines during the 1850s and subsequent decades. Overall, this simple comparison in means suggest that municipalities with railway access grew on average 0.25 to 0.55 percentage points faster per year than unconnected municipalities.

Table 2.4: Annual Population Growth Rates by Railway Access Status in 1864

	Pre-Railway Sample[a]				Whole Switzerland[a]				Nodes[b]	
	Obs.	Rail Mean	No Rail Mean	Diff.	Obs.	Rail Mean	No Rail Mean	Diff.	Obs.	Mean
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1800–37	903	0.89	0.92	−0.03						
		(0.49)	(0.48)	(0.04)						
1837–50	903	0.60	0.66	−0.07						
		(0.71)	(0.89)	(0.08)						
1850–60	903	0.13	−0.017	0.30**	2811	0.57	0.02	0.55***	33	1.63
		(0.87)	(1.06)	(0.09)		(1.26)	(1.14)	(0.06)		(1.32)
1860–70	903	0.59	0.20	0.39***	2827	0.47	0.22	0.25***	33	1.60
		(0.88)	(1.26)	(0.09)		(1.25)	(1.04)	(0.06)		(1.16)
1870–80	898	0.46	−0.06	0.52***	2788	0.45	−0.02	0.47***	33	1.34
		(0.96)	(1.03)	(0.09)		(1.11)	(1.09)	(0.06)		(1.04)

Notes: Means and comparison of means for the first wave of railway construction (1847-1864). Columns (4) and (8) present a two-sided T-test of the difference in means of municipalities with railway access to those without railway access. ***a:*** Sample excludes nodes and municipalities strongly affected by railway construction work (source: Rey, 2003, 147-149). ***b:*** Sample includes all 20 largest towns nodes and Stephenson & Swinburne nodes. Standard deviations in parentheses in columns (2), (3), (6), (7), and (10). Standard errors in parentheses in columns (4) and (8). + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

In order to identify the causal impact of railway access on population growth rates, we now turn to our econometric analysis which is discussed in four subsections. The main evaluation concerns annual population growth at the municipal level, which is presented first. Discussing results on cross-section (section 2.5.1) and panel data (section 2.5.2) regressions, we complement the advantages of both approaches. In section 2.5.3 we attempt to get a clearer grasp of the heterogeneity of effects. The obvious question that arises is whether the construction of the railway infrastructure benefited all connected communes equally or led to a concentration of economic activity and divergence in the municipalities' growth rates. Furthermore, we analyse displacement effects of railway access on nearby municipalities. Finally, section 2.5.4 completes the municipality analysis by evaluating the robustness of results for population growth at the district level, and examining whether the railway induced population growth is due to migration or birth surpluses. It also presents evidence of railway access accelerating structural change and increasing the body height of conscripts.

2.5.1 Cross-Sectional Analysis: Population Growth in Municipalities

The cross-sectional analysis focusing on railway lines constructed between 1847 and 1864 is presented first, followed by a discussion on the second wave of railway development that lasted

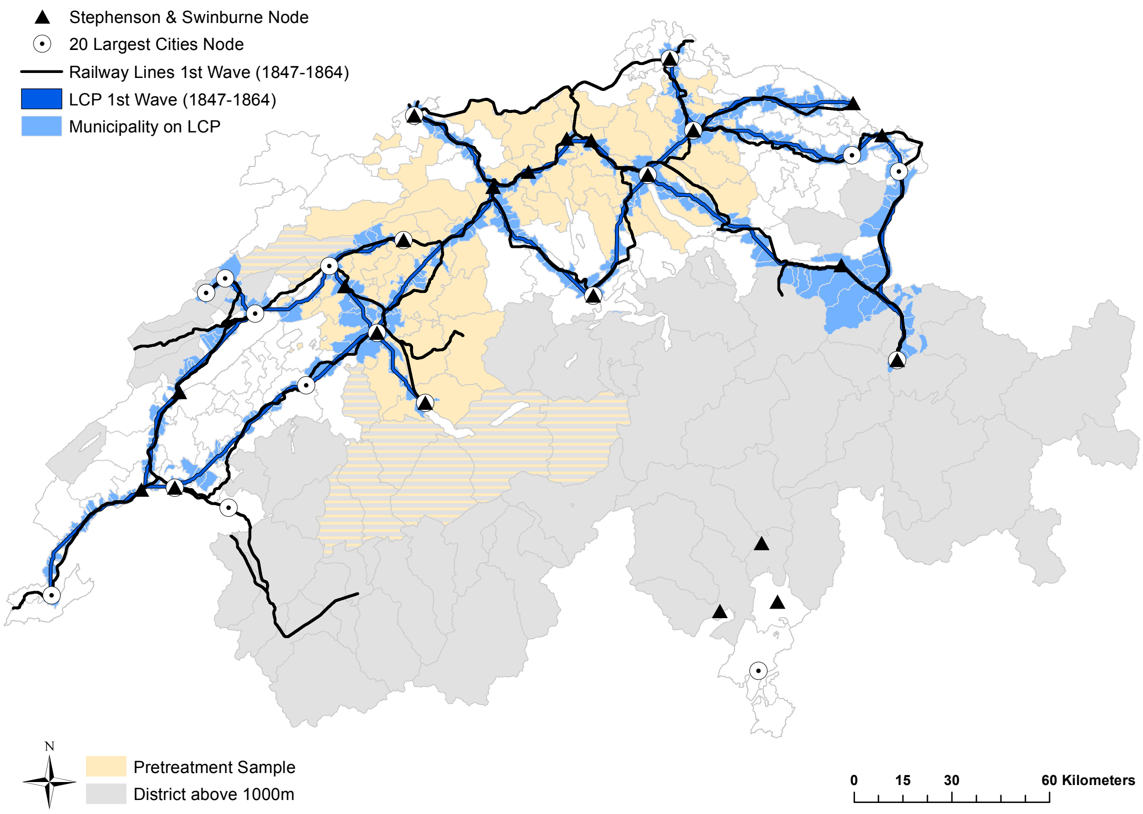


Figure 2.3: Railway Lines and Least-Cost Paths, 1^{st} Wave

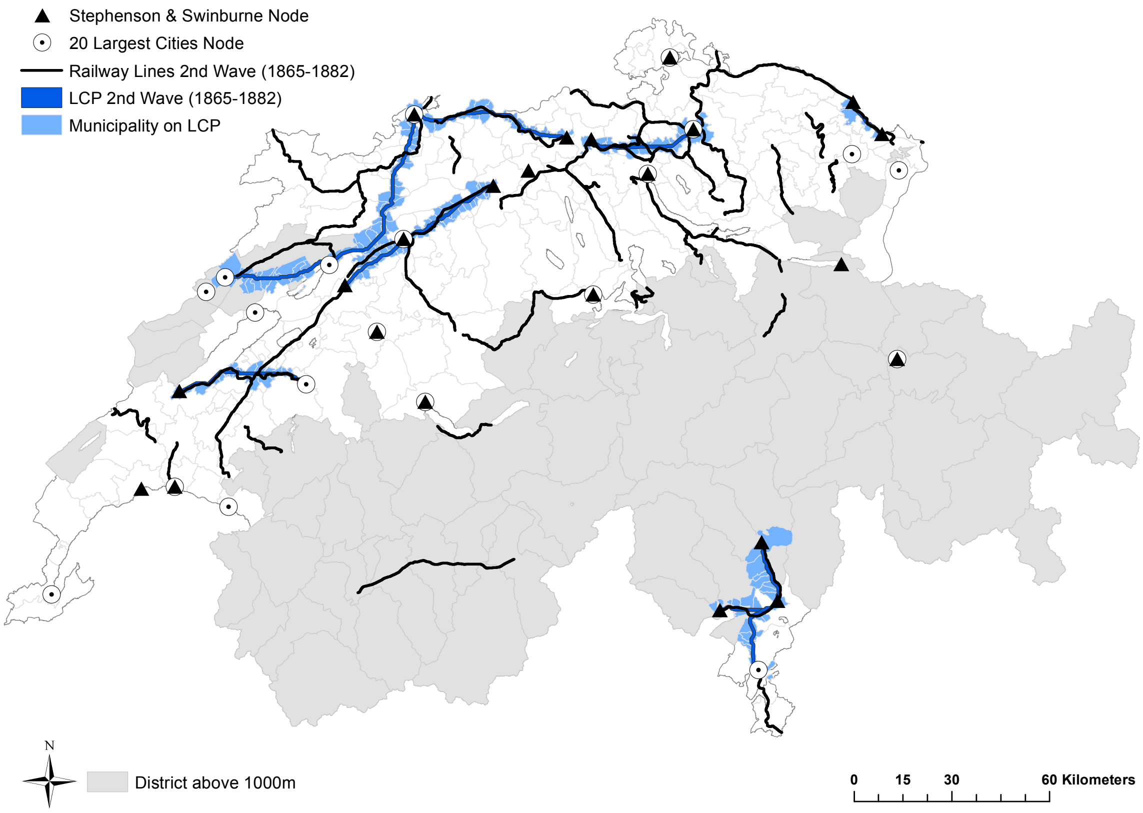


Figure 2.4: Railway Lines and Least-Cost Paths, 2^{nd} Wave

from 1869 to 1882. Our benchmark results are based on a sample including all the municipalities of Switzerland, except for the 33 main transport nodes and municipalities that experienced extraordinary demographic volatility due to railway construction work.

Table 2.5 presents the findings for the *first wave* of railway expansion (1847–1864), illustrated in Figure 2.3. The first column reports results for a placebo test based on the pre-railway period between 1800 and 1850. Both the OLS and IV coefficients for the pretreatment period are close to zero and statistically insignificant. This indicates that conditional on our control variables, population growth rates in treated and untreated municipalities were similar previous to the railway era. This changed following the construction of the railway network. Column (2) captures the effects of railway lines on long-term population growth between 1850 and 1900. Municipalities that were connected to the railway network between 1847 and 1864 experienced a significant increase in population growth during the second half of the 19th century.

Table 2.5: The Impact of Railway Access (1847–64) on Annual Population Growth Rates, Cross-Sectional Estimates at the Municipal Level

	Long Run		10 Year Periods				
	1800–50[a]	1850–1900	1850–60	1860–70	1870–80	1880–90	1890–1900
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
OLS: Annual Population Growth Rates and Railway Access							
Rail Access 1847–64	0.00	0.41***	0.31***	0.26***	0.36***	0.34***	0.56***
	(0.04)	(0.04)	(0.06)	(0.07)	(0.06)	(0.06)	(0.08)
R^2	0.26	0.28	0.17	0.07	0.11	0.11	0.12
Observations	903	2770	2791	2790	2748	2743	2769
IV, Second Stage: Annual Population Growth Rates and Railway Access							
Rail Access 1847–64	0.15	0.39***	–0.06	0.31*	0.58**	0.32+	0.47*
	(0.15)	(0.10)	(0.15)	(0.15)	(0.18)	(0.18)	(0.22)
Observations	903	2770	2791	2790	2748	2743	2769
IV, First Stage: Actual Railway Access 1847–64 and Least-Cost Paths							
LCP 1847–64	0.25***	0.33***	0.41***	0.40***	0.35***	0.34***	0.33***
	(0.04)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
R^2	0.29	0.39	0.33	0.33	0.37	0.37	0.39
Observations	903	2770	2791	2790	2748	2743	2769

Notes: The dependent variable is annual population growth in percent. The controls used are distance to the nearest town node (log), distance to the nearest Stephenson-Swinburne node (log), subsequent railway access (binary), access to main road (binary), access to navigable water (binary), elevation (log), water power potential (binary), town privilege (binary), population in 1850 (log), area in km^2 (log), annual district population growth 1800–1850, and cantonal fixed effects. ***Sample:*** All municipalities of Switzerland, excluding nodes and municipalities strongly affected by railway construction work (source: Rey, 2003, 147-149). ***a***: Pre-railway sample available for four cantons (ZH, BE, SO, AG). The instrument is based on a least-cost path for railway lines between the 20 largest cities and Stephenson-Swinburne nodes. Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

The IV estimates, shown in the middle panel of Table 2.5, imply an additional annual growth of 0.39 percentage points, which translates into a relative population increase of over 20% within 50 years. An average municipality with early railway access and 750 inhabitants in 1850 would therefore have gained around 160 additional inhabitants by 1900 compared to an identical municipality without railway access. Note that the first stage, which is presented in the table's bottom panel, yields a strong and highly significant correlation between the instrument and the railway access variable. This alleviates concerns related to weak instruments.

Looking at every decade individually, we obtain fairly stable coefficients. According to our

Table 2.6: The Impact of Railway Access (1869–82) on Annual Population Growth Rates, Cross-Sectional Estimates at the Municipal Level

	Long Run		10 Year Periods				
	1850–70[a]	1870–1900	1850–60[a]	1860–70	1870–80	1880–90	1890–1900
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
OLS: Annual Population Growth Rates and Railway Access							
Rail Access 1869–82	0.24***	0.36***	0.24***	0.19**	0.32***	0.23***	0.42***
	(0.05)	(0.04)	(0.07)	(0.06)	(0.06)	(0.07)	(0.08)
R^2	0.15	0.22	0.15	0.07	0.09	0.11	0.11
Observations	2344	2344	2365	2364	2324	2320	2344
IV, Second Stage: Annual Population Growth Rates and Railway Access							
Rail Access 1869–82	–0.08	0.51**	0.01	–0.19	0.37	0.60*	0.49
	(0.19)	(0.18)	(0.27)	(0.23)	(0.29)	(0.26)	(0.35)
Observations	2344	2344	2365	2364	2324	2320	2344
IV, First Stage: Actual Railway Access 1869–82 and Least-Cost Paths							
LCP 1869–82	0.36***	0.36***	0.37***	0.37***	0.35***	0.36***	0.36***
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
R^2	0.32	0.32	0.29	0.29	0.27	0.28	0.32
Observations	2344	2344	2365	2364	2324	2320	2344

Notes: The dependent variable is annual population growth in percent. The controls used are distance to the nearest town node (log), distance to the nearest Stephenson-Swinburne node (log), subsequent railway access (binary), access to main road (binary), access to navigable water (binary), elevation (log), water power potential (binary), town privilege (binary), population in 1850 (log), area in km^2 (log), cantonal fixed effects, and population growth 1850–1860 (except for columns ***a***, where district population growth 1800–1850 is used). ***Sample:*** All municipalities, excluding nodes and municipalities strongly affected by railway construction work (source: Rey, 2003, 147-149). The instrument is based on a least-cost path for railway lines between the 20 largest cities and Stephenson-Swinburne nodes. Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

preferred IV estimates in columns (4) to (7), municipalities with railway access experienced additional annual growth of 0.31 to 0.58 percentage points compared to municipalities without a railway connection. This effect is significant at the 10% level or higher, except for the first decade of railway construction from 1850 to 1860 suggesting that railway access impacted population growth with a time lag. The OLS and IV coefficients are similar in magnitude, which substantiates the claim that early railway companies prioritised direct connections between large cities, and did not necessarily target fast growing municipalities along the way.

The results for the *second wave* of railway construction (1869–1882), which expanded the network by another 1 500 km of tracks, are presented in Table 2.6. Municipalities that gained railway access by 1864 were excluded from these regressions. Again, the first stage results for the IV models yield large and highly significant correlations between our instrument and railway access.

Columns (1), (3), and (4) display placebo tests based on an analysis of population growth rates from 1850 to 1870 and railway access obtained between 1869 and 1882. The OLS regressions produce a positive and statistically significant correlation, indicating that municipalities with a higher population growth rate in this pre-treatment period were more likely to receive railway access between 1869 to 1882. The IV approach seems to mitigate this issue, with coefficients being close to zero or negative and statistically insignificant in both the short (1850–60; 1860–70) and long run perspective (1850–70).

While pre-treatment annual growth rates are not correlated with the instrumented railway access indicator, we obtain strong correlations for the post-treatment period. Estimates for the long run effect spanning 30 years from 1870 to 1900 are displayed in the second column and show a positive and highly significant effect of railway access on population growth, with the IV estimate amounting to 0.51. Columns (5) to (7) report the analogous results for each decade separately, which display positive effects of railway access across all specifications, while in two cases the coefficients are insignificant with t-values between 1.3 and 1.4. The effects of railway access on population growth rates vary between 0.37 and 0.6 percentage points. As for the results on the first wave of railway expansion, the post-treatment IV estimates are not statistically different from the OLS estimates in this second set of cross-sectional regressions.

Tables B.2 and B.3 in the appendix (section 2.6) present the same set of results for municipalities belonging to districts with a mean elevation below 1 000 m.a.s.l. Although population growth dynamics might be different in the barren alpine regions, the main estimates are not substantially affected by this robustness exercise.

Taken together, the results for both waves of railway construction suggest that railway access caused an increase in annual population growth rates, with the average effect lying between 0.39 and 0.51 percentage points for our preferred long run IV specifications. The following section analyses the impact of railway access on population growth based on panel data techniques.

2.5.2 Panel Data Analysis: Population Growth in Municipalities

The cross-section estimations include various control variables that account for municipality specific characteristics. Nevertheless, unobserved characteristics may still influence the particular growth potential of a municipality. The fixed effect estimation allows us to base inference on within municipality variation, which eliminates biases from time-invariant unobserved characteristics. Table 2.7 presents our preferred panel estimations that use the lag of railway access as main explanatory variable.

We provide results for OLS and IV fixed effects estimations for three different samples. The first sample includes all the municipalities in Switzerland (see column 1 & 2). The second sample excludes municipalities where the mean district elevation is higher than 1 000 m.a.s.l. in order to remove the barren alpine region (see column 2 & 3). The third sample is restricted to municipalities for which pre-railway population data is available, so that the decade from 1840 to 1850 can be included in the estimation as well (see column 3 & 4). For all samples the main nodes and municipalities affected by railway construction work are excluded.

The IV coefficients in columns (2), (4) and (6) range between 0.41 to 0.44 for all three samples and are statistically significant at the 5% level or higher. Remarkably, they are also very close to the long run effects estimated in the cross section (first wave: 0.39, second wave: 0.51). Although this effect is less than half of the estimates reported for cities (see Hornung, 2015; Berger and Enflo, forthcoming), it is not negligible. A coefficient of 0.42 translates into an additional population count of 23% after 50 years for municipalities that got connected to the railway infrastructure compared to municipalities without railway access. In the next

Table 2.7: The Impact of Railway Access on Annual Population Growth Rates, Panel Estimates at the Municipal Level

	Whole Switzerland[a]		Below 1 000 m[b]		Pre-Treatment Sample[c]	
	OLS FE	IV FE	OLS FE	IV FE	OLS FE	IV FE
	(1)	(2)	(3)	(4)	(5)	(6)
Annual Population Growth Rates in Decade t and Railway Access in Decade $t-1$						
Lag Railway Access	0.08*	0.42**	0.13**	0.41**	0.29***	0.44*
	(0.04)	(0.13)	(0.04)	(0.13)	(0.06)	(0.18)
R^2	0.05	–	0.05	–	0.17	–
Municipalities	2731	2731	2020	2020	821	821
Observations	13651	13651	10100	10100	4926	4926
Municpality FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Canton Time FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The dependent variable is annual population growth rate in percent. Full sample, ***a:*** All municipalities of Switzerland, excluding nodes and municipalities strongly affected by railway construction work (source: Rey, 2003, 147-149). Below 1 000 m sample, ***b:*** All municipalities of districts with mean elevation below 1 000 m.a.s.l., excluding nodes and municipalities strongly affected by railway construction work (see Rey, 2003, 147-149). ***c:*** This estimation additionally includes the pre-treatment period 1837–1850, but is restricted to a smaller sample of municipalities for which pre-railway population data is available (four cantons: ZH, BE, SO, AG), excluding nodes and municipalities strongly affected by railway construction work (source: Rey, 2003, 147-149). The instrument is based on a least-cost path for railway lines between the 20 largest cities and Stephenson-Swinburne nodes. Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

section, we explore local displacement effects of railway and impact heterogeneity across treated municipalities.

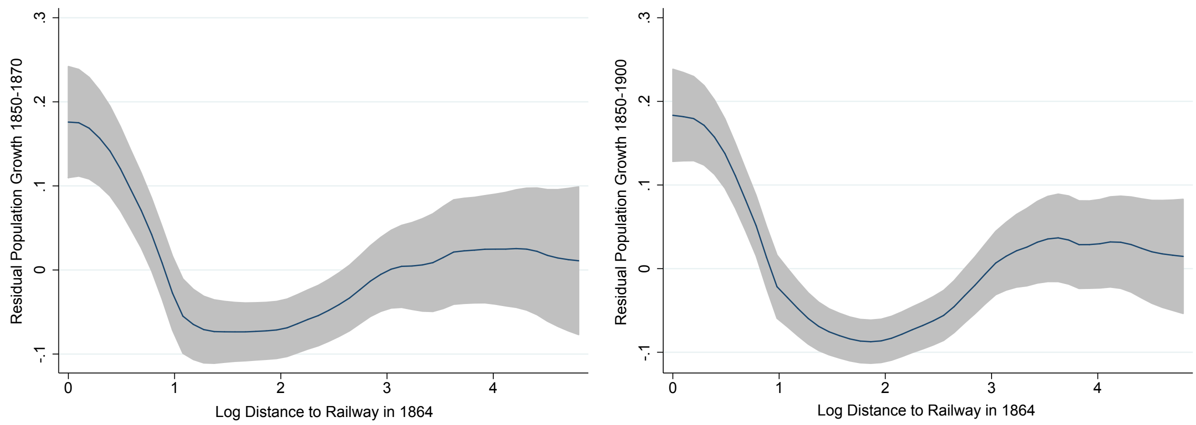
2.5.3 Displacement Effects and Heterogeneity across Municipalities

Compared to other studies that investigate the impact of railway infrastructure, the small size of Swiss municipalities allows for a detailed spatial evaluation of growth effects. For example, both Atack et al. (2010) and Donaldson and Hornbeck (forthcoming) use US counties as units of analysis, which have a median land area of 1 610 km^2 compared to less than 7 km^2 of a median-sized Swiss municipality.[24] Hornung (2015), on the other hand, uses Prussian cities as unit of analysis, and therefore provides no insights for railway effects in rural areas.

One important question that can be addressed based on the spatially small-scaled data relates to the local displacement effects of transportation infrastructure. For instance, Chandra and Thompson (2000) find that US highways led to a local shift of production from unconnected regions to neighbouring regions with highway access. If railway caused such local reorganisations, we would expect negative population growth effects in close proximity to the railway. Figure 2.5 shows two local polynomial regression of residual growth on the log distance to the railway in 1864, covering the periods from 1850 to 1870 and from 1850 to 1900. Both graphs are indeed hump-shaped, supporting the hypothesis of local displacement effects from nearby municipalities to those with direct railway access.

To further investigate this claim, Table B.8 in the appendix reconstructs our baseline cross-section results, yet provides a spatially disaggregated analysis by including a set of distance

[24]Information on the area of US counties is based on the US Census 2000 available at `http://factfinder.census.gov/`; the area of Swiss municipalities is based on our own calculations in GIS using the Swiss boundary files.



(a) Distance to Railway in 1864 and Population Growth from 1850 to 1870

(b) Distance to Railway in 1864 and Population Growth from 1850 to 1900

Figure 2.5: Distance to Railway and Population Growth, Local Polynomial with 95% Confidence Band. **Settings:** Kernel: Epanechnikov, Degree=0, Bandwith (a)=0.46 (b)=0.43, Pwidth (a)=0.7 (b)=0.64
Residuals: Calculated based on OLS regression of population growth (1850–1870; 1850–1900) on control variables, i.e. distance to the nearest town node (log), distance to the nearest Stephenson-Swinburne node (log), access to main road (binary), access to navigable water (binary), elevation (log), water power potential (binary), town privilege (binary), population in 1850 (log), area in km^2 (log), and annual district population growth 1800–1850, and cantonal fixed effects.

dummies. Distance to the railway is calculated as distance between a municipality's geographic centroid and the closest railway track, with each distance dummy covering a band with a width of 2 km.[25] Railway only had a positive growth impact on municipalities that either had direct access to the railway network, or were very close to the railway line. Reproducing the results from the local polynomial regressions, municipalities located more than 2 km from the railway network experienced a slowdown in population growth with the negative effect peaking at 6 to 8 km. Taken together, this strongly points towards a local reorganisation of economic activity as municipalities in the direct vicinity of railway tracks (2 km–10 km) experienced slowing population growth, suggesting that people moved closer to the railway line after it went into service.

With regard to effect heterogeneity, it is interesting to investigate whether large municipalities benefited more from railway access in terms of population growth than small ones, as the *home-market channel* from economic geography models would suggest. In Table 2.8 we therefore add an interaction term of railway access with population size prior to the railway construction in 1850. Column (2) presents both OLS and IV estimates including that interaction term. The estimated coefficient turns out to be small and insignificant at conventional levels. Consequently, one may conclude that municipality size was not a key moderating factor for the impact of railway access, thus rejecting implications related to the home-market effect.

Urbanisation in Switzerland advanced quickly in the second half of the 19th century, as Figure 2.1a unambiguously illustrates. This may raise concerns that the effect of railway access was

[25] We only present OLS results for this part, since instrumenting a series of distance dummies is beyond the power of our instrument. Considering the results in Tables 2.4 and 2.5 we are not too concerned about selection issues. Moreover, selection is probably even less likely for the set of municipalities that were close to the railway tracks but did not gain direct access. Indeed, the results in column (1) of Table B.8 do not point towards selection effects.

Table 2.8: The Impact of Railway Access (1847–64) and Interaction Terms on Annual Population Growth Rates, Cross-Sectional Estimates at the Municipal Level

	Long Run 1850–1900		
	(1)	(2)	(3)
OLS: Annual Population Growth and Railway Access			
Rail Access 1847–64	0.41***	0.40***	0.40***
	(0.04)	(0.04)	(0.04)
Rail Access 1847–64 x Population 1850		0.05	
		(0.04)	
Rail Access 1847–64 x Distance 20 Cities			−0.07
			(0.06)
R^2	0.28	0.28	0.28
Observations	2770	2770	2770
IV: Annual Population Growth and Railway Access			
Rail Access 1847-64	0.39***	0.35**	0.38***
	(0.10)	(0.12)	(0.10)
Rail Access 1847–64 x Population 1850		0.08	
		(0.10)	
Rail Access 1847–64 x Distance 20 Cities			−0.05
			(0.14)
Observations	2770	2770	2770
FS 1: F-statistic	146.87	81.99	86.01
FS 2: F-statistic	–	67.62	76.78

Notes: The dependent variable is the annual population growth rate in percent. The controls used are distance to the nearest town node(log), distance to the nearest Stephenson-Swinburne node (log), subsequent railway access (binary), access to main road (binary), access to navigable water (binary), elevation (log), water power potential (binary), town privilege (binary), population in 1850 (log), area in km^2 (log), annual district population growth 1800–1850, and cantonal fixed effects. ***Sample:*** All municipalities of Switzerland, excluding nodes and municipalities strongly affected by railway construction work (source: Rey, 2003, 147-149). The instrument is based on a least-cost path for railway lines between the 20 largest cities and Stephenson-Swinburne nodes. Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

mainly driven by urbanisation forces. We therefore check whether the impact of railway access varies with distance to the urban centres. While distance to the 20 largest cities certainly has a strongly negative impact on population growth rates as seen in Table B.1 in the appendix, the interaction of distance to the 20 largest cities with railway access has no significant effect on the population growth rate. This alleviates concerns that the railway access dummy primarily picks up urbanisation effects, and suggests that railway access was equally beneficial in peripheral areas and in the direct vicinity of the main urban centres.

Finally, we investigate the impact of railway access at different percentiles of the population growth distribution using quantile regressions. As Figure B.1 in the appendix reveals, railway access increased population growth across all percentiles evaluated, with somewhat stronger effects on faster growing municipalities.

Overall, our results at the municipal level show that railway moderately increased population growth in directly connected municipalities. This impact was fairly homogeneous across municipalities of different sizes, different geographical locations, and different percentiles of the growth distribution. However, our findings also suggest that unconnected municipalities in the close vicinity of railway lines experienced a slump in population growth rates, probably due to displacement effects, as reported for highways by Chandra and Thompson (2000) for instance.

2.5.4 District Level: Population Growth, Migration, Sectoral Work Shares, and Body Height

This section reports and discusses the estimation results based on district data. While studying the municipal level provides a cleaner setup for identification, district data allows for a number of extensions. *First*, the previously discussed results raise the question of whether railway had a positive net impact on local population growth, or simply led to a local zero-sum-shift from municipalities without railway access to municipalities with railway access. District level data can shed light on this question, as one would expect a positive impact of railway access on district population growth in the first scenario only. *Second*, Swiss municipality data does not reveal whether changes in the population count are driven by changes in migration, birth surpluses, or both. Census data including district birth and death statistics can be used to examine the two channels separately. *Third*, one may test the hypothesis that railway access promoted regional economic development based on further indicators alongside population growth. District statistics on sectoral work shares and the body height of conscripts allow us to gain insights into the impact of railway on structural change and the biological well-being of the Swiss population. This last step may also provide answers to the question why railway expansion affected population dynamics, since shifts in labour demand and altered living conditions are potential drivers of migrations flows.

We use the population weighted share of municipalities directly connected to the railway network as our main explanatory variable on the district level. Reflecting the three waves of railway constructions in 19th century Switzerland, we define three measures that indicate the *additional* railway access gained by districts in each period, i.e. $RASHR^{1847-64}$, $RASHR^{1865-82}$, and $RASHR^{1883-99}$.[26] These three railway variables are used as main explanatory variables in our OLS regressions of the form

$$Y_{ic}^{t} = \alpha_5 + \gamma_1 RASHR_{ic}^{47-64} + \gamma_2 RASHR_{ic}^{65-82} + \gamma_3 RASHR_{ic}^{83-99} + \varphi_5 D_{ic}^{1850} + \kappa_{5c} + \vartheta_{ic}, \quad (2.5)$$

where Y_{ic} stands for the outcome of interest in period t, κ_c denotes cantonal fixed effects, and D_{ic}^{1850} is a vector of district control variables, including the population weighted log distance to the nearest city, population weighted access to a main road, log mean district elevation, log population in 1850, and population growth between 1800 and 1850. We do not report the results for the IV equivalent of equation (2.5), since a test for weak instruments along Stock and Yogo (2005) suggests that instrumenting $RASHR_{ic}^{47-64}$ and $RASHR_{ic}^{65-82}$ would be unreliable due to low first stage correlations.

[26] We calculate the population weighted share of municipalities with railway access for each year and district. $RASHR_i^{1847-64}$ stands for district's i population weighted share of municipalities with railway access in 1864. $RASHR_i^{1865-82}$ gives district's i population weighted share of municipalities with railway access in 1882 minus its population weighted share of municipalities with railway access in 1864. Finally, $RASHR_i^{1883-99}$ is district's i population weighted share of municipalities with railway access in 1899 minus its population weighted share of municipalities with railway access in 1882.

We complement the cross-sectional analysis with OLS and IV district fixed effects panel estimations, the latter being specified as

$$RASHR_{ict} = \pi_{6i} + \beta_6 LCPSHR_{ict} + \lambda_{6t} + \lambda_{6t} \cdot \kappa_{6c} + \xi_{ict}, \text{ and} \tag{2.6}$$

$$Y_{ict} = \pi_{7i} + \beta_7 \widehat{RASHR}_{ict-1} + \lambda_{7t} + \lambda_{7t} \cdot \kappa_{7c} + \varepsilon_{ict} \tag{2.7}$$

where time fixed effects, λ_t, control for population growth cycles on the national level, and cantonal-time fixed effects, $\lambda_t \cdot \kappa_c$, account for cycles on the regional level. $LCPSHR_{ict}$ serves as instrument, which is defined as the population weighted share of municipalities in district i and decade t that lie on the least-cost path explained in section 2.4.2.

Table 2.9 shows the district level distribution of railway access. During the first wave of railway construction 84 of the 178 Swiss districts were connected to the railway network, and by 1900 this number increased to 158. The districts' average share of people living in a municipality with railway access climbed to 26% by 1864, and reached 55% by the end of the century. With respect to our main explanatory variable $RASHR^w$, this translates into district averages of 26% for the first wave, 19% for the second wave, and 10% for the third wave. These numbers are used in the remainder of this study for back-of-the-envelope calculations of impact magnitudes for districts with average railway access compared to identical districts without a railway connection.

Table 2.9: Share of Population with RW-Access, District Level Distribution

	Mean across Districts		Number of Districts with	
w	Marginal[a]	Cumulative	No Access (=0)	Full Access (=1)
1847–64	0.26	0.26	84	3
1865–82	0.19	0.45	34	8
1883–99	0.10	0.55	20	10

Notes: *a* This column shows the mean across the explanatory variable $RASHR^t$.

Did these railway improvements affect *population growth* at the district level, as observed for municipalities? The results in Table 2.10 indeed suggest that railway access had a positive net-impact on district population growth, and did not simply lead to a local zero-sum-shift from municipalities without railway access to municipalities with railway access. A district that was fully connected to the railway network experienced an average increase in the annual population growth rate of 0.4 to 0.8 percentage points compared to districts without railway access, which is slightly larger than the effects found at the municipal level. The panel-IV coefficient is rather imprecisely estimated, however, and is insignificantly different from our preferred municipality estimates, which range from 0.4 to 0.5. Furthermore, the equivalent coefficient for the sub-sample of districts with mean elevation below 1 000 m.a.s.l. is 0.63 (see Table C.1 in the appendix), and therefore halves the gap to the municipality estimates. While we find significant and robust correlations between railway access and population growth across different models and sub-samples, a placebo test based on district population growth prior to the railway era in column

Table 2.10: The Impact of Railway Access on Annual Population Growth Rates, Cross-Sectional and Panel Estimates at the District Level

	Cross Section			Panel FE	Panel IV FE	IV FS
	1800–50	1850–1900		1850–1900	1850–1900	1850–1900
	(1)	(2)		(3)	(4)	(5)
RASHR 1847–64	0.18	0.52***	Lag RASHR	0.41**	0.84+	
	(0.12)	(0.15)		(0.15)	(0.43)	
RASHR 1865–82	0.14	0.70***	LCPSHR			0.43***
	(0.13)	(0.17)				(0.09)
RASHR 1883–99	0.05	0.61**				
	(0.12)	(0.22)				
R^2	0.58	0.49	R^2 (within)	0.33	–	0.73
Observations	136	126	Observations	600	600	600
			Districts	120	120	120

Notes: The dependent variable is the annual population growth rate in percent. *RASHR* is defined as the share of a district's population that lives in a municipality with direct access to the railway network. The controls used are distance to the nearest node (log, population weighted), access to main road (population weighted), mean district elevation (log), population in 1850 (log), and population growth 1800–1850. The sample comprises all districts, except for districts including one of the 33 nodes, and districts strongly affected by railway construction work (source: Rey, 2003, 147-149). The instrument is based on a least-cost path for railway lines between the 20 largest cities and Stephenson-Swinburne nodes. The first stage regression is shown in the last column. *LCPSHR* is the population weighted share of municipalities in a district that lie on the least-cost path. Panel estimations include district fixed effects, year fixed effects and year-cantonal fixed effects. Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

(1) does not yield significant coefficients for the railway access variables.

The previous findings unequivocally suggest that gaining railway access increased population growth. In a next step, we explore whether the additional growth is driven by larger *birth surpluses* or the *migration balance*. Based on the districts' birth and death statistics as reported in the Swiss census since 1870, we calculate the birth surplus as well as the migration balance for each decade and district as a share of the districts' populations. The cross-sectional and panel OLS regressions presented in Table 2.11 yield a positive correlation between railway access and the migration balance as well as the excess of birth over death counts. Comparing a district without railway infrastructure to an identical district with average railway access, the cross sectional estimates in column (1) translate into a railway induced increase in the net migration rate of 2.1% of the initial population within 10 years.[27] The panel estimates in column (3) are quantitatively similar to the cross-sectional results and suggest that connecting 55% of a district's population to the railway network would cause an increase in the net migration balance of 2.8 percentage points in the following decade. Turning to the second measure, average railway access is associated with an increase in the district's birth surplus of 0.5% to 1% of its initial population depending on the regression model used.[28]

As both dependent variables are measured in terms of a district's population, these results indicate that railway access had a considerably larger impact on the migration balance than on the birth surplus. Having said this, it should be noted that the migration balance was negative for three out of four districts between 1870 and 1900. Hence, improved railway access had a positive impact of population growth rates because it cushioned the outflow of people to urban centres rather than causing a net inflow. In summary, one may conclude that railway access had

[27] Based on the cross-sectional results, the ten-year effect of railway access on the migration balance of an average district is calculated based on Table 2.9 and 2.11 as follows: $(0.26 \cdot 10.18 + 0.19 \cdot 15.44 + 0.1 \cdot 7.26)/3 = 2.1$.

[28] Based on the cross-sectional results, the ten-year effect of railway access on the birth surplus of an average district is calculated based on Table 2.9 and 2.11: $(0.26 \cdot 3.52 + 0.19 \cdot 3.68 + 0.1 \cdot 0.83)/3 = 0.5$.

Table 2.11: The Impact of Railway Access on Migration and Birth Surplus, Cross-Sectional and Panel Estimates at the District Level

	Cross Section (1870–1900)			Panel FE (1870–1900)	
	Migration[a]	Birth Surplus[b]		Migration[a]	Birth Surplus[b]
	(1)	(2)		(3)	(4)
RASHR 1847–64	10.18^{+}	3.52**	Lag RASHR	5.06*	1.79*
	(5.82)	(1.22)		(2.02)	(0.84)
RASHR 1865–82	15.44*	3.68**			
	(6.36)	(1.32)			
RASHR 1883–99	7.26	0.83			
	(5.90)	(2.08)			
R^2	0.54	0.63	R^2 (within)	0.30	0.32
Observations	112	112	Observations	327	327
			Districts	109	109

Notes: *RASHR* is defined as the share of a district's population that lives in a municipality with direct access to the railway network. Dependent variable, ***a***: A district's net balance of migration flow, indicates inflow - outflow. ***b***: A district's birth surplus as a share of average population. Railway access is measured by the share of the population that has access (municipalities with railway line) to the railway network. The sample comprises all districts, except for districts including one of the 33 main nodes, and districts strongly affected by railway construction work (source: Rey, 2003, 147-149). The controls used in the cross-section estimation are distance to the nearest city (log, population weighted), access to main road (population weighted), mean district elevation (log), population in 1850 (log), and population growth 1800–1850. Cross-section estimations include cantonal fixed effects. Panel estimations include district fixed effects, year fixed effects and year-cantonal fixed effects. Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

a weakly positive impact on the birth surplus and at the same time significantly improved the migration balance by attenuating the net outflow of people. Overall, these two effects translate on average into an additional annual population growth rate of 0.4 to 0.8 percentage points caused by full railway access.

In a last step, we complement the analysis of population growth by examining the impact of railway infrastructure on the *sectoral composition* and the *biological standard of living.* These two variables allow us to evaluate whether the conclusions derived from the population statistics are robust to the use of other proxies of regional economic development. Furthermore, we may learn why railway expansion affected population dynamics; railway induced changes in labour demand and living conditions could have been two potential factors shaping Switzerland's domestic migration flows.

While historians have discussed various channels through which railway infrastructure potentially accelerated structural change, to our knowledge no study has so far aimed to quantify these effects in the Swiss context. One important consequence of railway expansion in Switzerland was the shift in agricultural production from grain to dairy products, as explained in section 2.2. Frey and Vogel (e.g. 1997, chapter 8) point out that international demand for dairy products and the availability of cheap grain from abroad made dairy farming financially more attractive. Since milk is highly perishable, quick and reliable transport from producers to the processing industry was crucial, making accessible regions better suited to this type of farming.[29] At the same time animal husbandry was less labour intensive than grain cultivation, meaning that the shift to dairy farming led to stagnating or even decreasing agricultural workforce numbers. On top of that, employees in the agricultural sector traditionally supplemented their income with

[29] Consider the first condensed milk producer in Switzerland as an illustrative example. It started operating in Cham, 20 km south of Zurich, two years after being connected to the railway network in 1864. In around 1880, it was supplied by 1350 farmers, absorbing more milk than Switzerland's largest city Zurich (Frey and Vogel, 1997, 279).

Table 2.12: The Impact of Railway Access on Sectoral Work Shares, Panel Estimates at the District Level

	Panel FE (1860–1900)			Panel IV FE (1860–1900)		
	Agriculture	Manufact.	Services	Agriculture	Manufact.	Services
	(1)	(2)	(3)	(1)	(2)	(3)
Lag RASHR	-7.74^{***}	6.26^{***}	1.48	-9.69^{+}	9.14^{+}	0.55
	(1.72)	(1.36)	(0.99)	(5.16)	(4.72)	(1.59)
R^2 (within)	0.54	0.48	0.51	–	–	–
Districts	117	117	117	117	117	117
Observations	550	550	550	550	550	550

Notes: *RASHR* is defined as the share of a district's population that lives in a municipality with direct access to the railway network. Dependent variable: A district's sectoral work share in percent (agriculture, manufacturing, services). The sample comprises all districts, except for districts including one of the 33 main nodes, and districts strongly affected by railway construction work (source: Rey, 2003, 147-149). The instrument is based on a least-cost path for railway lines between the 20 largest cities and Stephenson-Swinburne nodes. Panel estimations include district fixed effects, year fixed effects and year-cantonal fixed effects. Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

home-based manufacturing work. With the advance of industrial mechanisation, driven among other things by large-scale coal imports via rail, this source of supplemental income began to vanish continuously. This process made farming jobs less attractive, and therefore potentially accelerated the decline in agricultural workforce numbers. On the other hand, railway access arguably offered opportunities in the manufacturing sector and service industry. For instance, the availability of cheap coal not only accelerated mechanisation, but also cleared the way for energy-intensive sectors such as steel works, salterns, and cement production (see section 2.2). Furthermore, railway infrastructure allowed industrial entrepreneurs to relocate to areas that offered cheap land and labour, without being penalised by uncompetitively high transport costs. The quintupling of freight volumes from 1870 to 1900 and the more than 350 privately owned – typically very short – interchange rail tracks illustrate how heavily manufacturers relied on this new means of transport.[30] Regarding services, the railway expansion coincided with a growing popularity of tourism and leisure activities. Early travel books such as "Baedeker's Schweiz" provide detailed accounts of train connections, documenting their attractiveness for (wealthy) tourists.[31] It is certainly no coincidence that nowadays well-known alpine sights like the "Rigi" (1 795 m.a.s.l.) at the Lake of Lucerne or the "Jungfraujoch" (3 466 m.a.s.l.) in Grindelwald were connected by rack railways from as early as 1871 and 1912.

We measure sectoral composition based on work shares of the agricultural, manufacturing, and service sector. The cross-sectional regressions aim to explain the percentage point change in sectoral work shares between 1860 to 1900 using our period specific district level measures for railway access along a set of controls. In the panel data models, the sectoral work shares for each decade are regressed on the lagged value of the time-variant railway access indicator, or its first-stage prediction in the IV setup.

[30]Statistics on freight and privately owned interchange tracks were obtained from the *Schweizerische Eisenbahnstatik* (SPE, 1900), which is partly accessible online from `http://www.bahndaten.ch/` (last access: 01.02.2016).

[31]Baedeker's Schweiz, which appeared in 31 revised editions between 1840 and 1905, began offering descriptions of localities and recommended routes with detailed travel directions, typically information on train connections such as train operator, journey time, fares, and interchange facilities. It also included a map of Switzerland's railway network, as well as a general section on traveling by train with information on fares, circular tickets, and Switzerland's official railway guide.

The cross-sectional regressions (see Table 2.13) and the panel models (see Table 2.12) reveal an unambiguous pattern. Improvements in the railway access of districts are associated with a shift from the agricultural sector to the manufacturing and services industries. The estimated coefficients imply that in districts with average railway access the agricultural work share declined by an additional 4.6 to 8.3 percentage points between 1860 and 1900 compared to districts without a railway connection.[32] At least two-thirds of this railway induced drop in agricultural employment were absorbed by an increase in the industrial workforce, while employment gains in the service sector compensated for one-third or less. Considering that the average drop in the agricultural work share was 9.2 percentage points in the same period, the drop explained by railway infrastructure improvements at the district level is substantial.

Although very few sources document industry-specific wages paid during the 19th century in Switzerland, the available records suggest that wages in the secondary sector were higher than in the primary sector.[33] Since better connected localities experienced on average a faster shift from agricultural employment to better paid manufacturing jobs, railway related sectoral change may explain why districts with well-developed railway infrastructure experienced higher population growth than districts with poor railway access. This notion also reflects a common narrative within the agrarian community at the time, which claimed that employment opportunities in the manufacturing sector and the promise of higher living standards in the city were responsible for the rural exodus, thus jeopardising the traditional social order (Gruner, 1987, 1404).

While fragmentary income data makes it impossible to investigate these claims further, the body height data of conscripts allow us to directly compare improvements in *living standards* across Switzerland. Since the 1970s, interdisciplinary research – known as new anthropometric history – established body height and other anthropometric measures as indicators for the biological standard of living.[34] The adult height of a population serves as a measure of the population's nutritional status from birth through adolescence. Early childhood and the adolescent growth spurt are considered sensitive periods, during which a person's stature is most keenly affected by nutritional abundance or scarcity (Steckel, 2009, 8). A broad list of factors influencing nutritional status and physical growth have been studied, including social class (e.g. Schoch, Staub and Pfister, 2012), business cycles (e.g. Sunder and Woitek, 2005), industrialisation (e.g. Steckel and Floud, 1997) and public infrastructure, such as sanitary and electric facilities (e.g. Thomas and Strauss, 1992) or road access (e.g. Gibson and Rozelle, 2003). These studies find

[32] Based on the cross-sectional results, the 40 year effect of railway access on the agricultural work share of an average district is calculated based on Table 2.9 and 2.13: $0.26 \cdot (-14.6) + 0.19 \cdot (-17.2) + 0.1 \cdot (-12.2) = -8.3$.

[33] The database *Historical Statistics of Switzerland Online* (`www.fsw.uzh.ch/histstat/`) compiles all industry specific income statistics available for the 19th century, its main sources being Brugger (1978) for the primary sector and Gruner (1987) for the secondary sector. While the database is relatively comprehensive for manufacturing jobs, wages paid in the agricultural sector are only available for the cantons of Geneva and Thurgau. A comparison of average incomes earned in various occupations and regions yields wage differences between the primary and secondary sector ranging from -20% (construction worker vs. senior farm labourer) to +250% (worker in horology industry vs. herdsman). By far most of these comparisons suggest that manufacturing jobs were better paid, even though we did not discount wages in the primary sector for the very poor employment opportunities during the winter months.

[34] Steckel (1995) reviews 145 articles on body height and human welfare written between the late 1970s and 1994, while Steckel (2009) covers 326 studies on this topic published between 1995 and 2008.

Table 2.13: The Impact of Railway Access on Sectoral Work Shares and Body Height, Cross-Sectional Estimates at the District Level

	Sectoral Shares (1860–1900)[a]				Body Height[b]
	Agriculture	Manufacturing	Services		1890–1910
	(1)	(2)	(3)		(4)
RASHR 1847–64	−14.56**	9.16**	4.89*		
	(4.48)	(3.44)	(2.32)		
RASHR 1865–82	−17.20***	12.35***	4.25*	RASHR 1847–82	0.17
	(4.65)	(3.61)	(2.14)		(0.29)
RASHR 1883–99	−12.22*	2.46	8.82*	RASHR 1882–99	0.93**
	(5.83)	(3.46)	(4.16)		(0.29)
R^2	0.49	0.54	0.39	R^2	0.73
Observations	123	123	123	Observations	125

Notes: *RASHR* is defined as the share of a district's population that lives in a municipality with direct access to the railway network. Dependent variable, ***a:*** Percentage point change in a district's sectoral work share (agriculture, manufacturing, services). ***b:*** Centimeter change in a district's conscripts average body height between 1884/91 and 1908/12. The controls used are distance to the nearest city (log, population weighted), access to main road (population weighted), mean district elevation (log), population in 1850 (log), population growth 1800–1850, and cantonal fixed effects. Additionally, models in columns ***a*** control for the district's sectoral work share in 1860 (agric., indust., services), while column ***b*** includes the district's average body height for the 1884/91 conscription. The sample comprises all districts, except for districts including one of the 33 main nodes, and districts strongly affected by railway construction work (source: Rey, 2003, 147-149). Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

that economically favourable conditions and well-developed infrastructure are positively correlated with nutrition intake and body height. The study closest to our analysis of body height is Solakoglu (2007), who evaluates the effect of railway on nutritional intake in the US postbellum period. Her findings suggest that railway infrastructure increased nutritional intake significantly. Relating her estimates to findings on calorie intake and body height by Craig and Weiss (1998), she computes a railway-induced average stature growth of an additional 1.1 cm between 1867 and 1906.

Railway access may have an impact on body height through various channels, including the price and availability of nutrition and medical treatment, the quantity and physical nature of labour during adolescence, as well as the dissemination of infectious diseases. To quantify the net impact of railway infrastructure on body height, we study body height data from two conscription periods (source: Staub, 2010). The first cross-section comprises the body height of men physically examined between 1884 and 1891, with their year of birth ranging from 1865 to 1872. The second cross-section includes the body height of men physically examined between 1908 and 1912, with their year of birth ranging from 1889 to 1893.[35] We intend to explain the change in body height of recruits between these two periods using the change in district railway access and a set of controls (Figure C.1 in the appendix illustrates the timing for this test). Since we use the change in body height between two conscription periods and control for the initial body height of recruits, one would expect that only the third wave of railway constructions, i.e. between 1883 to 1899, has explanatory value. On one hand, recruits registered in the first military survey available (1884 to 1891) were at least 11 years old by the time the earliest of these railway lines went into service so that possible railway induced improvements in their nutritional status were hardly sufficient to translate into body height gains. On the other hand,

[35] Although the Swiss military authorities surveyed conscripts' body measurements every year, regional averages were computed and documented by the statistical office for multi-year periods only. The data from the years 1884 to 1891 and 1908 to 1912 are the earliest records available that can be used in a district comparison; see Staub (2010, 101–102) for details.

men recruited in the second period (1908 to 1912) were at most 10 years old when the last third-wave lines entered into operation, which allowed their stature to be affected by the benefits of improved railway access during childhood and the adolescent growth spurt.

The last column of Table 2.13 shows the results for the regression of body height changes in centimetres on railway access at the district level. As hypothesised, railway access prior to 1883 is not significantly correlated with changes in the districts' average body height between the two conscription rounds, while railway improvements between 1883 to 1899 are associated with a highly statistically significant growth effect. According to the coefficient for *RASHR 1883–99*, the average body height of young men increased by an additional 9.3 mm if they were domiciled in a district that gained full railway access between 1883 and 1899 compared to contemporaries living in a district without improvements in railway access.[36] This implies an additional gain in the conscripts' average body height of 1 mm for districts with average railway improvements between 1883 and 1899 relative to districts without additional railway connections in the same period. Compared to the average increase in body height across districts in the same period, which is 2.2 cm, these railway induced gains in body height were only marginal, however.

In summary, the regression results for all indicators of regional economic development analysed in this section indicate that railway improvements had a positive and statistically significant impact. In comparison to districts without any railway connections, those districts with average railway access experienced a moderate increase in population growth per year (around 0.2 to 0.4 percentage points), a substantially accelerated structural change in the economy (additional 4.6 to 8.3 percentage point shift in work shares from the primary to the secondary/tertiary sector), and a minor gain in biological well-being. Hence, the results for both the municipal and district levels support the hypothesis that railway access promoted regional economic development.

2.6 Conclusion

This paper investigates how railway infrastructure affects regional development by studying railway expansion and population growth in Switzerland during the second half of the 19th century. We find that the annual population growth rates of municipalities with access to the railway network were about 0.4 percentage points higher than annual the growth rates of municipalities without a railway connection. This result proves to be very robust to adjustments in the econometric framework (*cross-section* and *panel IV*), changes in the sample (*whole of Switzerland* and *lowlands*), examinations of different construction periods (*1847–1864* and *1869–1882*), as well as adaptations in the spatial units considered (*municipalities* and *districts*). The positive effect of railway access on population growth was markedly localised, however, as we find strong evidence for displacement effects: Municipalities in the vicinity of railway tracks but without direct access experienced the lowest population growth, suggesting that people moved closer to the railway line after it went into service. The district analysis of birth, death, and

[36] Restricting the sample to districts with a mean elevation of less than 1 000 m.a.s.l. (see column 4 in Table C.3 in the appendix) yields almost identical results.

migration statistics confirm that railway primarily had an impact on population growth via the local migration balance.

We supplement the analysis on population growth with an evaluation of two potential drivers behind migration flows, namely industrialisation inferred from sectoral work shares and improved living conditions measured via the body height of conscripts. Our estimates consistently show that the share of agricultural labour decreased substantially faster in districts with above-average railway access, while the same districts experienced an accelerated growth in manufacturing employment. Concerning body height, our estimations based on recruitment data yield a weakly positive but highly statistically significant effect of railway improvements between two conscription rounds and the gain in the recruits' average body height per district during that period. These findings signify that railway facilitated industrialisation and improved living conditions. Both factors – themselves indicators of regional development – likely drove migration towards better connected localities, as highlighted both by our municipality and district results on population growth.

Adding to the well-established findings on railway access and city growth, our study of Switzerland complements the recent literature on the impact of early railway lines in western countries. We show that not only urban centres but also small rural municipalities along the main lines benefited from railway access. While the estimated effects in rural areas are less than half that reported for cities, our findings do not strictly support the home-market hypothesis, as we find no evidence pointing towards a growth slowdown in peripheral municipalities after they received access to the railway network.

A. Appendix: Data

Control Variables

Table A.1: Variable Description & Data Sources

Municipal Level		
Annual Population Growth	$100 \cdot (log(POP_{i,t2}) - log(POP_{i,t1}))/(t2 - t1)$	Census (1850, 60, 70, 80, 88, 1900), Schuler and Schluchter (in progress)
Treatment Variable		
Railway Access	Binary indicator. Equals one if railway intersects a municipality's boundary.	GIS-Dufour (Egli et al., 2005)
Control Variables		
Distance to Town Node	Natural logarithm of the distance between a municipality's centroid and the closest town node's centroid in kilometers. Town nodes are defined as Switzerland's 20 largest towns in 1850.	Swisstopo (2007)
Distance to Stephenson-Swinburne Node	Natural logarithm of the distance between a municipality's centroid and the closest Stephenson-Swinburne node in kilometers. If the closest Stephenson-Swinburne node is also a town node, we compute the distance based on the second closest Stephenson-Swinburne node.	Swisstopo (2007)
Access to Main Road in 1850	Binary indicator. Equals one if road of primary importance intersects a municipality's boundary, see 2.6.	GIS-Dufour (Egli et al., 2005)
Access to Navigable Water	Binary indicator. Equals one if municipality adjoins navigable water.	Swisstopo (2007)
Elevation	Natural logarithm of the mean elevation (in 100m) calculated based on a 25 m x 25 m height model.	Swisstopo (2004)
Water Power Potential	Binary indicator. Equals one if a river with a water flow of at least 1 m^3/s crosses a municipality and – in doing so – overcomes a height difference of 10m or more, see 2.6.	Swisstopo (2007), Pfaundler and Schönenberger (2013)
Town Privilege	Binary indicator. Equals one if municipality holds the historical town status.	Guyer (1960)
Population in 1850	Natural logarithm of a municipality's population in 1850.	Census (1850)
Municipal Area	Natural logarithm of municipal area in square kilometers.	Swisstopo (2007)
District Pop. Growth 1800–50	$100 \cdot (log(POP_{d,t2}) - log(POP_{d,t1}))/50$	Schluchter (1988), Census
District Level		
Annual Population Growth	$100 \cdot (log(POP_{d,t2}) - log(POP_{d,t1}))/(t2 - t1)$	Census (1850, 60, 70, 80, 88, 1900)
Migration Balance	$100 \cdot (POP_{d,t2} - POP_{d,t1} - Birthsurplus_{d,t1-2})/(POP_{d,t1})$	Census (since 1870)
Birth Surplus	$100 \cdot (\#Births_{d,t1-2} - \#Deaths_{d,t1-2})/(\frac{1}{2}POP_{d,t1} + \frac{1}{2}POP_{d,t2})$	Census (since 1870)
Work Share: Agriculture	*Cross-Section*: Percentage point change in work share of agric. sector 1860–1900; *Panel*: Work share in agric. sector	Census (since 1860)
Work Share: Manufacturing	*Cross-Section*: Percentage point change in work share of industrial sector 1860–1900; *Panel*: Work share in industrial sector	Census (since 1860)
Work Share: Services	*Cross-Section*: Percentage point change in work share of service industry 1860–1900; *Panel*: Work share in service industry	Census (since 1860)
Change in Body Height of Conscripts	Centimeter change in a district's conscripts average body height between 1884/91 and 1908/12	Staub (2010)
Treatment Variable		
Pop. Share with Railway Access	Population (as per 1850) weighted share of municipalities that had direct access to the railway network	GIS-Dufour (Egli et al., 2005)
Standard Control Variables		
Mean Distance to Town Node	Population weighted (as per 1850) minimal distances from a district's municipalities to the nearest city-node.	Swisstopo (2007), Census
Pop. Share with Road Access	Share of population (as per 1850) with direct access to road of primary importance.	GIS-Dufour (Egli et al., 2005)
Elevation	Mean elevation (in 100m) of district calculated based on a 25 m x 25 m height model.	Swisstopo (2004)
Population in 1850	Natural logarithm of a district's population in 1850.	Census (1850)
District Pop. Growth 1800–50	$100 \cdot (log(POP_{d,t2}) - log(POP_{d,t1}))/50$	Schluchter (1988), Census
Additional Control Variables		
Work Share in 1860	A district's work share in agriculture/industry/services in 1860	Census (since 1860)
Body Height of Conscripts in 1884/91	A district's conscripts average body height as measured between 1884–91.	Staub (2010)

Table A.2: Descriptive Statistics

Municipal Level	Observations	Mean	Std. Dev.	Min.	Max.
Annual Population Growth, 1850–1900 (cross-section)	2844	0.15	0.66	−2.43	5.90
Annual Population Growth, 1850–1900 (pooled)	14 330	0.15	1.27	−16.05	22.23
Treatment Variable					
Railway Access, 1850–1900 (pooled)	17 322	0.22	-	0	1
Control Variables					
LN(Distance to Town Node)	2854	2.90	0.63	0.68	4.44
LN(Distance to Stephenson-Swinburne Node)	2854	3.08	0.74	0.21	4.64
Access to Main Road in 1850	2887	0.38	-	0	1
Access to Navigable Water	2887	0.06	-	0	1
LN(Elevation in 100m)	2887	1.97	0.49	0.78	3.40
Water Power Potential	2887	0.42	-	0	1
Town Privilege	2887	0.04	-	0	1
LN(Population) in 1850	2847	6.25	0.92	3.56	10.64
LN(Municipal Area)	2887	2.00	1.04	−1.14	5.64
District Level	Observations	Mean	Std. Dev.	Min.	Max.
Annual Population Growth, 1850–1900 (cross-section)	178	0.35	0.48	−6.00	2.36
Annual Population Growth, 1850–1900 (pooled)	944	0.51	1.85	−4.50	51.10
Migration Balance, 1870–1900 (cross-section)	143	−12.11	16.39	−44.83	40.12
Migration Balance, 1870–1900 (pooled)	429	−4.09	6.59	−29.30	24.60
Birth Surplus, 1870–1900 (cross-section)	143	7.40	3.40	−9.60	15.59
Birth Surplus, 1870–1900 (pooled)	429	7.40	3.72	−13.42	20.02
Δ Work Share: Agricult., 1860–1900 (cross-section)	161	−9.17	9.70	−36.22	14.97
Work Share: Agricult., 1860–1900 (pooled)	784	51.27	19.23	2.18	96.24
Δ Work Share: Manuf., 1860–1900 (cross-section)	161	4.09	8.49	−16.34	29.04
Work Share: Manuf., 1860–1900 (pooled)	784	36.32	17.15	2.43	84.12
Δ Work Share: Services, 1860-1900 (cross-section)	161	5.07	4.00	−2.28	26.96
Work Share: Services, 1860–1900 (pooled)	784	12.41	6.59	1.33	50.17
Δ Body Height of Conscripts, 1884/91–1908/12	176	2.16	0.99	0.00	6.00
Treatment Variable					
Pop. Share with Railway Access, 1850–1900 (pooled)	1068	0.35	0.34	0	1
Standard Control Variables					
LN(Mean Distance to Town Node) in 1850	158	3.00	0.57	1.59	4.27
Pop. Share with Road Access in 1850	178	0.76	0.21	0	1
LN(Elevation in 100m)	178	2.12	0.52	1.20	3.26
LN(Population) in 1850	178	9.32	0.62	7.30	11.07
Annual Population Growth, 1800–1850 (cross-section)	175	0.69	0.31	−0.30	1.49
Additional Control Variables					
Work Share: Agriculture in 1860	149	55.06	17.57	7.85	92.84
Work Share: Manufacturing in 1860	149	35.45	15.95	4.64	76.58
Work Share: Services in 1860	149	9.49	4.72	2.52	32.39
Body Height of Conscripts in 1884/91	176	163.40	1.47	159.4	166.9

Road Network

We use information on the development of the road network in the 18th and 19th century from the GIS-Dufour project (Egli et al., 2005). GIS-Dufour documents all roads and their classification according to the cantonal road laws. The road laws were enacted in most cantons in the years 1830–1840 and they differ from canton to canton. However, most cantonal laws include at least a classification on roads of primary importance, i.e. class 1 roads. To control for road accessibility we use information on the class 1 road network, and identify municipalities with access to a class 1 road. Figure A.2 shows the first class road network in the year 1850.

Potential for Water Power Generation

Early Swiss industrial development used hydropower as an important source to run industrial machines. Since Switzerland itself had no coal deposits, wood was a limited power source and there was no high-capacity means of transportation for fossil fuels, water was the main source of power for industrial development prior to the railway era (Schnitter, 1992). By the year 1876 Switzerland had hydroelectric power plants installed with a capacity of 70 350 horse power (Weissenbach, 1876). For each municipality we define a potential for hydroelectric power based on existing hydropower technologies. The main parameters determining the potential for hydropower are the water cumulative flows and the gradient that the water falls. The Francis Turbine was invented in the year 1849 by James B. Francis and the most advanced technology at the beginning of the railway era in Switzerland. Taking the technical constraints of the Francis Turbine into account, we define a simplified indicator for hydro power potential based on two conditions: First, the water flow has to reach a minimum of at least 1 m^3/s. Second, the height difference between the point of entry and exit of a river flowing through a municipality has to be at least 10 m. If a watercourse satisfying both conditions runs through a municipality, it is assigned value 1, and otherwise 0. We construct this variable based on detailed information on water drain measured for each water body in Switzerland combined with data on larger river water flows measured by metering stations.[1] Using GIS we determine for every water body the point of entry and exit for each municipality and the height difference between entry and exit point. We then code municipalities as having the potential for industrial hydropower generation using the parameters mentioned above.

[1]Data on water drain is available at http://www.bafu.admin.ch/wasser/13462/13496/15016/index.html?lang=de (Pfaundler and Schönenberger, 2013); data from metering stations along larger Swiss rivers is available at http://www.hydrodaten.admin.ch/de/stationen-und-daten.html.

Maps

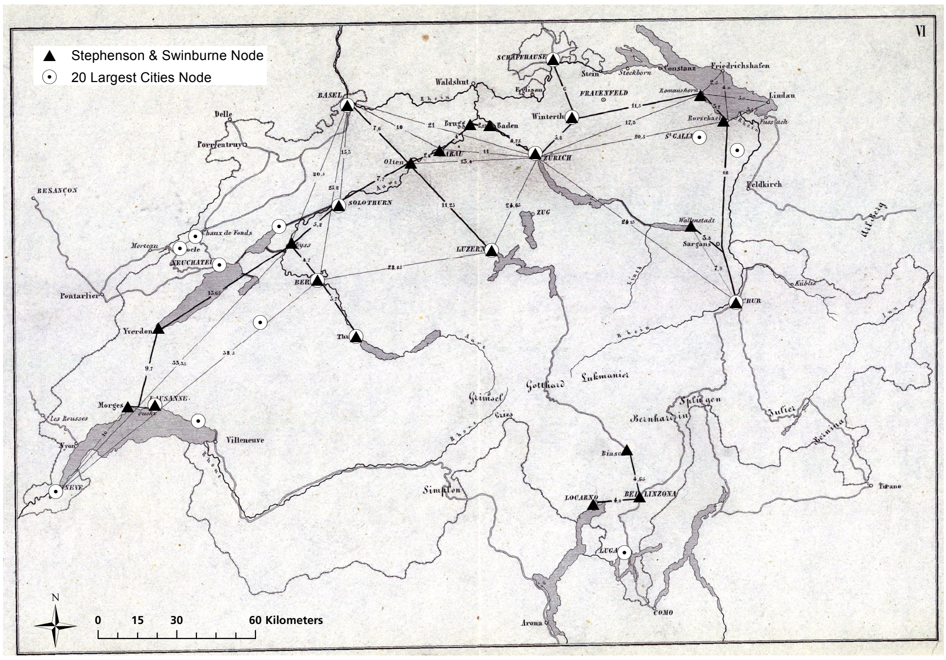


Figure A.1: Original Stephenson & Swinburne Plan with Main Nodes

Notes: The figure displays the original Stephenson & Swinburne railway plan and the selected main nodes. The selection of nodes is based on the proposed traffic hubs of Stephenson & Swinburne and the 20 largest municipalities in the year 1850 that had the town privilege. Some towns were both a hub in the original Stephenson & Swinburne plan and belonged to the 20 largest cities in 1850.

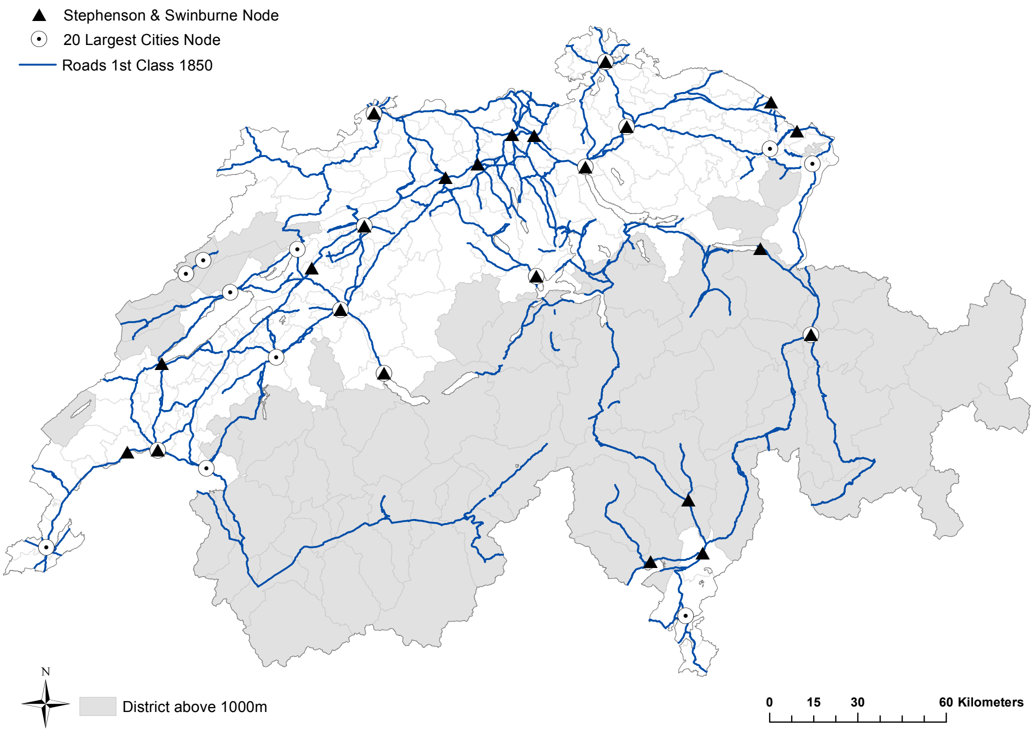


Figure A.2: Roads of Primary Importance in 1850

Notes: Road network displaying roads with a classification 1 according to the cantonal road laws in 1850, based on the GIS-Dufour project (Egli et al., 2005).

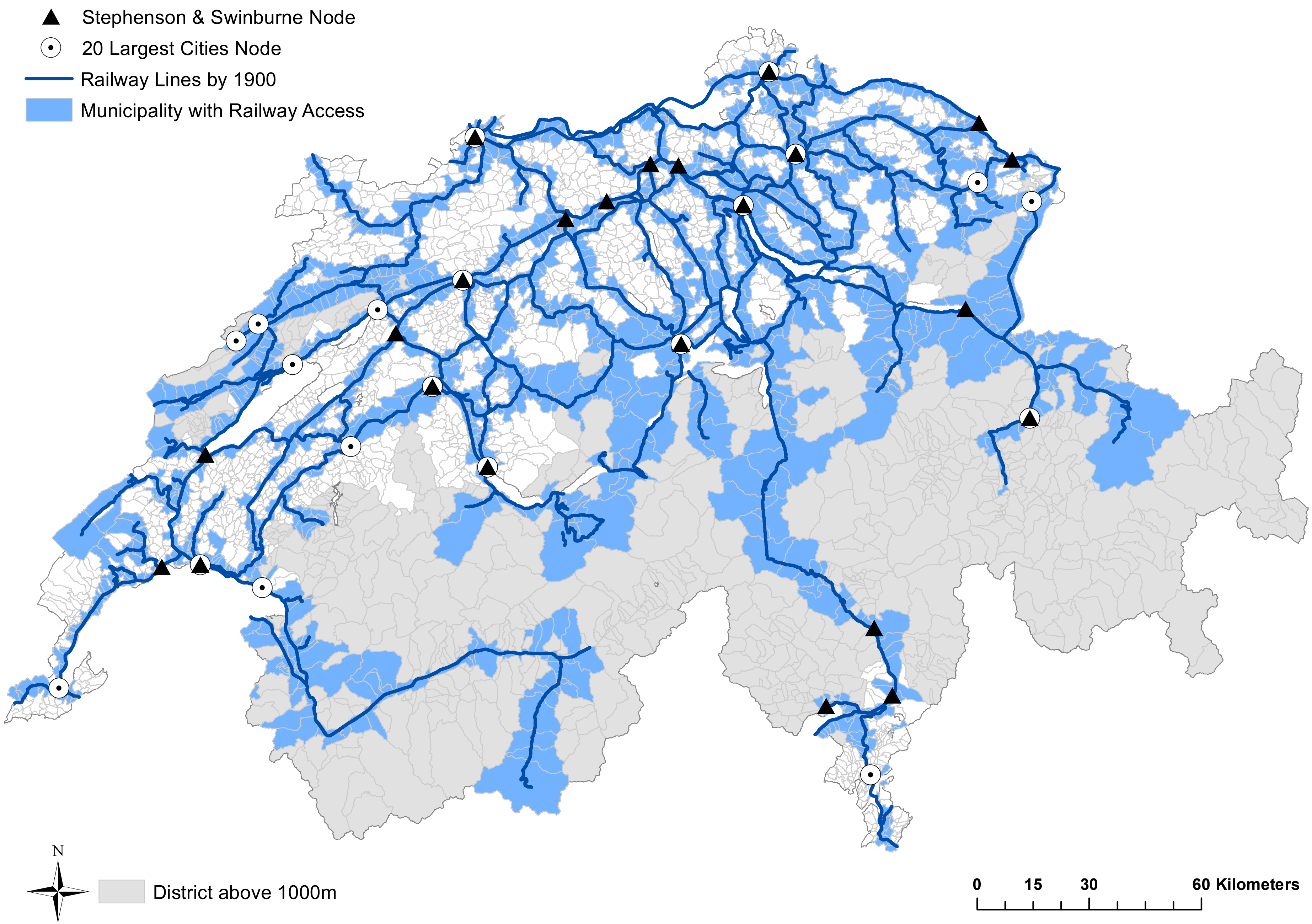


Figure A.3: Swiss Railway Network by 1900

Notes: The map shows the Swiss railway network as completed by 1900. The source of digitized railway lines is the project "GIS-Dufour" (Egli et al., 2005).

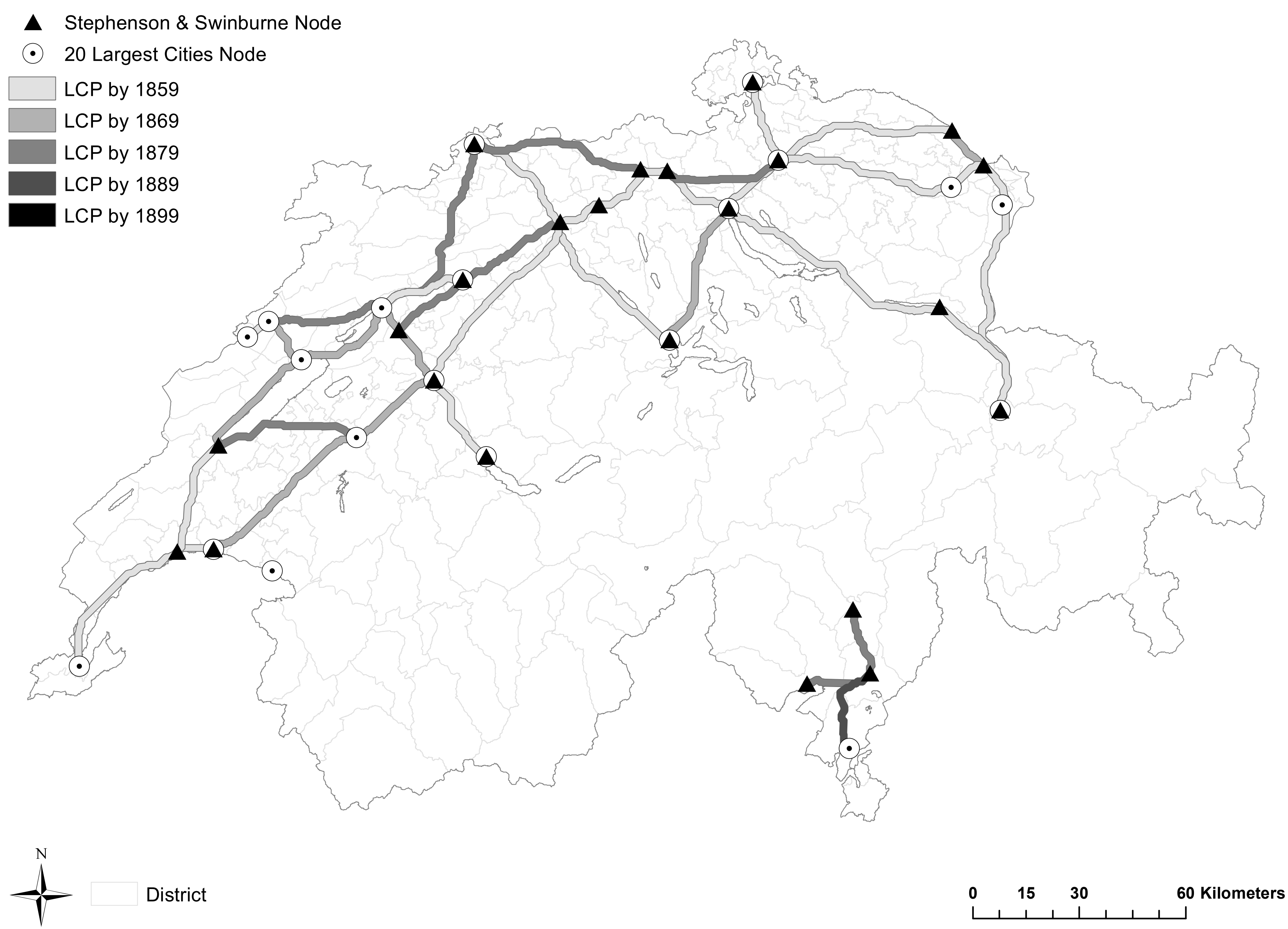


Figure A.4: Least-Cost Paths for Main Lines by Decade of Their Opening

Notes: Least-cost paths, which represent a virtual cost-efficient railway line computed with GIS-software. For better readability least-cost paths are displayed with a width of 2km.

Sample of Districts

Table A.3: Sample of Districts across Different Dependent Variables

ID	District	ID	District	ID	District	ID	District
Canton Zurich		**Canton of Schwyz**		**Canton of St. Gallen**		**Canton of Ticino**	
101	Affoltern	501	Einsiedeln	1701	St. Gallen^{n,s,b}	2101	Bellinzona^{n,c}
102	Andelfingen	502	Gersau	1702	Rorschach^{n}	2102	Blenio
103	Bülach	503	Höfe	1703	Unterrheintal	2103	Leventina^{c}
104	Dielsdorf^{s,b}	504	Küsnacht	1704	Oberrheintal^{n}	2104	Locarno^{n,c}
105	Hinwil	505	March	1705	Werdenberg	2105	Lugano^{n,c}
106	Horgen	506	Schwyz^{c,b}	1706	Sargans^{n}	2106	Mendrisio
107	Meilen	**Canton of Obwalden**		1707	Gaster	2107	Riviera^{n,c}
108	Pfäffikon	600	Obwalden	1708	See	2108	Vallemaggia
109	Uster	**Canton of Nidwalden**		1709	Obertoggenburg	**Canton of Vaud**	
110	Winterthur^{n,b}	700	Nidwalden	1710	Neutoggenburg	2201	Aigle
111	Zürich^{n,s,b}	**Canton of Glarus**		1711	Alttoggenburg	2202	Aubonne
Canton of Bern		800	Glarus	1712	Untertoggenburg	2203	Avenches
201	Aarberg^{n}	**Canton of Zug**		1713	Wil	2204	Cossonay
202	Aarwangen^{s,b}	900	Zug^{c}	1714	Gossau^{n,s,b}	2205	Echallens
203	Bern^{n,b}	**Canton of Fribourg**		**Canton of Grisons**		2206	Grandson
204	Biel^{n,s,b}	1001	Broye	1801	Albula^{c}	2207	Lausanne^{n,b}
205	Büren	1002	Glane	1802	Bernina	2208	Lavaux
206	Burgdorf	1003	Gruyere	1803	Glenner^{c,s}	2209	Morges^{n}
207	Courtelary	1004	Saane^{n}	1804	Heinzenberg^{c}	2210	Moudon^{n,b}
208	Delemont^{b}	1005	See	1805	Hinterrhein^{c}	2211	Nyon
209	Erlach	1006	Sense	1806	Imboden^{c,s}	2212	Orbe
210	Franches-Montagne	1007	Veveyse	1807	Inn	2213	Oron
211	Fraubrunnen	**Canton of Solothurn**		1808	Maloja^{c}	2214	Payerne
212	Frutigen^{c}	1101	Balsthal	1809	Moesa	2215	Enhaut
213	Interlaken	1102	Bucheggb.-Kriegst.	1810	Müstair	2216	Rolle
214	Konolfingen^{s}	1103	Dorneck-Thierstein	1811	Oberlandquart	2217	Vallée
215	Laufen	1104	Olten-Goesgen^{n}	1812	Plessur^{n}	2218	Vevey^{n}
216	Laupen	1105	Solothurn-Lebern^{n}	1813	Unterlandquart^{c}	2219	Yverdon^{n}
217	Moutier	**Canton of Basel-Stadt**		1814	Vorderrhein^{s}	**Canton of Valais**	
218	La Neuveville	1200	Basel^{n,b}	**Canton of Aargau**		2301	Brig^{c}
219	Nidau^{s,b}	**Canton of Basel-Land**		1901	Aarau^{n}	2302	Conthey
220	Oberhasli	1301	Arlesheim^{b}	1902	Baden^{n}	2303	Entremont
221	Porrentruy	1302	Liestal	1903	Bremgarten	2304	Goms
222	Saanen	1303	Sissach	1904	Brugg^{n}	2305	Hérens
223	Schwarzenburg	1304	Waldenburg	1905	Kulm	2306	Leuk
224	Seftigen	**Canton of Schaffhausen**		1906	Laufenburg^{s}	2307	Martigny
225	Signau	1401	Oberklettgau^{s}	1907	Lenzburg^{c}	2308	Monthey
226	Simmental, Nieder-^{c}	1402	Reiat^{s}	1908	Muri^{c}	2309	Raron^{c}
227	Simmental, Ober-	1403	Schaffhausen^{n,s}	1909	Rheinfelden	2310	Saint-Maurice
228	Thun^{n,s,b}	1404	Schleitheim	1910	Zofingen	2311	Sierre
229	Trachselwald	1405	Stein	1911	Zurzach^{s}	2312	Sion
230	Wangen^{s,b}	1406	Unterklettgau^{s}	**Canton of Thurgau**		2313	Visp
Canton of Lucerne		**Canton of Appenzell (AR)**		2001	Arbon^{n,s}	**Canton of Neuchatel**	
301	Entlebuch^{s,b}	1501	Hinterland^{p}	2002	Bischofszell^{p,s,b,h}	2401	Boudry^{s}
302	Hochdorf	1502	Mittelland^{p}	2003	Diessenhofen	2402	Chaux-de-Fonds^{n}
303	Luzern^{n,b}	1503	Vorderland^{p}	2004	Frauenfeld^{p,s,b,h}	2403	Locle^{n}
304	Sursee^{s,b}	**Canton of Appenzell (AI)**		2005	Kreuzlingen^{p,s,b,h}	2404	Neuchatel^{n}
305	Willisau	1600	Appenzell	2006	Münchwilen^{p}	2405	Val-de-Ruz^{s}
Canton of Uri				2007	Steckborn^{p,s,b,h}	2406	Val-de-Travers
400	Uri^{c}			2008	Weinfelden^{p,s,b,h}	**Canton of Geneva**	
						2500	Geneva^{n,b}

Notes: ***n:*** Districts including one of the 33 main nodes. Excluded in all regression models. ***c:*** Districts that were affected by railway construction work in a given decade (see Rey, 2003, 147–149). Observation is excluded in all regressions covering the concerned period. ***p:*** Population data for 1800 cannot be merged reliably for these districts. Observation is excluded in all cross-section regressions. ***s:*** The employment data cannot be merged reliably for these districts, at least in certain decades. Observation is excluded in regressions with sectoral composition as dependent variable covering the concerned period. ***b:*** The birth and death statistics cannot be merged reliably for these districts, at least in certain decades. Observation is excluded in regressions with migration or birth surplus as dependent variable covering the concerned period. ***h:*** The body height data cannot be merged reliably for these districts, at least in certain decades. Observation is excluded in regressions with body height as dependent variable covering the concerned period.

B. Empirical Appendix: Municipality Level

Table B.1: The Impact of Railway Access (1847–64) on Annual Population Growth Rates (1850–1900), Cross-Sectional Estimates at the Municipal Level

	OLS (1)	IV (2)	IV, First Stage (3)
Railway Access 1847–64	0.41^{***}	0.39^{***}	
	(0.04)	(0.10)	
LCP 1847–64			0.33^{***}
			(0.03)
Road Access 1850	0.05^{*}	0.06^{+}	0.16^{***}
	(0.02)	(0.03)	(0.01)
Water Access	0.07	0.07	0.13^{***}
	(0.06)	(0.06)	(0.03)
Log Elevation	-0.25^{***}	-0.25^{***}	-0.07^{**}
	(0.05)	(0.05)	(0.02)
Water Power Potential	0.09^{***}	0.09^{***}	0.04^{**}
	(0.03)	(0.03)	(0.01)
Log Distance to Town Node	-0.24^{***}	-0.24^{***}	–0.02
	(0.03)	(0.03)	(0.01)
Log Distance to Steph.-Swinb. Node	0.04^{+}	0.04^{+}	–0.01
	(0.02)	(0.02)	(0.01)
Log Population 1850	–0.05	–0.05	0.07^{***}
	(0.03)	(0.03)	(0.01)
Log Area	0.12^{***}	0.12^{***}	–0.01
	(0.03)	(0.03)	(0.01)
Town Privilege	0.36^{***}	0.36^{***}	0.07^{+}
	(0.07)	(0.07)	(0.04)
Subsequent Railway Access	0.29^{***}	0.28^{***}	-0.23^{***}
	(0.03)	(0.04)	(0.01)
District Pop. Growth 1800–50	–1.58	–1.58	1.41
	(7.45)	(7.41)	(2.62)
R^2	0.28	–	0.39
Observations	2770	2770	2770

Notes: The dependent variable is annual population growth in percent. ***Sample:*** All municipalities, excluding nodes and municipalities strongly affected by railway construction work (source: Rey, 2003, 147-149). The instrument is based on a least-cost path for railway lines between the 20 largest cities and Stephenson-Swinburne nodes. Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

Robustness: Municipalities in Districts below 1 000 Meters

Table B.2: The Impact of Railway Access (1847–64) on Annual Population Growth Rates, Cross-Sectional Estimates (Sample: Mean District Elevation below 1 000 m.a.s.l.)

	Long Run		10 Year Periods				
	1800–50[a]	1850–1900	1850–60	1860–70	1870–80	1880–90	1890–1900
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
OLS: Annual Population Growth Rates and Railway Access							
Rail Access 1847–64	–0.02	0.42***	0.37***	0.21**	0.45***	0.37***	0.56***
	(0.04)	(0.04)	(0.07)	(0.08)	(0.07)	(0.07)	(0.08)
R^2	0.27	0.30	0.12	0.07	0.14	0.14	0.17
Observations	826	2018	2018	2018	2000	2000	2018
IV, Second Stage: Annual Population Growth Rates and Railway Access							
Rail Access 1847–64	0.13	0.42***	0.12	0.34*	0.62**	0.38+	0.38
	(0.16)	(0.12)	(0.17)	(0.16)	(0.21)	(0.20)	(0.25)
Observations	826	2018	2018	2018	2000	2000	2018
IV, First Stage: Actual Railway Access 1847–64 and Least-Cost Paths							
LCP 1847–64	0.24***	0.31***	0.39***	0.39***	0.33***	0.32***	0.31***
	(0.05)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
R^2	0.29	0.37	0.31	0.31	0.35	0.36	0.37
Observations	826	2018	2018	2018	2000	2000	2018

Notes: The dependent variable is annual population growth in percent. The controls used are distance to the nearest town node (log), distance to the nearest Stephenson-Swinburne node (log), subsequent railway access (binary), access to main road (binary), access to navigable water (binary), elevation (log), water power potential (binary), town privilege (binary), population in 1850 (log), area in km^2 (log), annual district population growth 1800–1850, and cantonal fixed effects. ***Sample:*** Municipalities of districts with a mean elevation below 1 000 m.a.s.l., excluding nodes and municipalities strongly affected by railway construction work (source: Rey, 2003, 147-149). ***a***: Pre-railway sample available for 4 cantons. The instrument is based on a least-cost path for railway lines between the 20 largest cities and Stephenson-Swinburne nodes. Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

Table B.3: The Impact of Railway Access (1869–82) on Annual Population Growth Rates, Cross-Sectional Estimates (Sample: Mean District Elevation below 1 000 m.a.s.l.)

	Long Run		10 Year Periods				
	1850–70[a]	1870–1900	1850–60[a]	1860–70	1870–80	1880–90	1890–1900
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
OLS: Annual Population Growth Rates and Railway Access							
Rail Access 1869–82	0.19***	0.38***	0.17*	0.18**	0.35***	0.28***	0.43***
	(0.05)	(0.05)	(0.07)	(0.06)	(0.07)	(0.07)	(0.08)
R^2	0.12	0.27	0.11	0.07	0.10	0.13	0.17
Observations	1669	1669	1669	1669	1653	1653	1669
IV, Second Stage: Annual Population Growth Rates and Railway Access							
Rail Access 1869–82	–0.38*	0.43*	–0.31	–0.45+	0.23	0.56*	0.48
	(0.19)	(0.17)	(0.25)	(0.24)	(0.29)	(0.26)	(0.32)
Observations	1669	1669	1669	1669	1653	1653	1669
IV, First Stage: Actual Railway Access 1869-82 and Least-Cost Paths							
LCP 1869-82	0.38***	0.38***	0.38***	0.39***	0.37***	0.37***	0.38***
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
R^2	0.33	0.33	0.30	0.30	0.29	0.30	0.33
Observations	1669	1669	1669	1669	1653	1653	1669

Notes: The dependent variable is annual population growth in percent. The controls used are distance to the nearest town node (log), distance to the nearest Stephenson-Swinburne node (log), subsequent railway access (binary), access to main road (binary), access to navigable water (binary), elevation (log), water power potential (binary), town privilege (binary), population in 1850 (log), area in km^2 (log), cantonal fixed effects, and population growth 1850–1860 (except for columns ***a***, where district population growth 1800–1850 is used). ***Sample:*** Municipalities of districts with mean elevation below 1 000 m.a.s.l., excluding nodes and municipalities strongly affected by railway construction work (source: Rey, 2003, 147-149). The instrument is based on a least-cost path for railway lines between the 20 largest cities and Stephenson-Swinburne nodes. Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

Robustness: Pre-Treatment Sample

Table B.4: The Impact of Railway Access (1847–64) on Annual Population Growth Rates, Cross-Sectional Estimates (Sample: Municipalities with Pre-Railway Data Available)

	Pre-Treatment			Post-Treatment
	1800–37[a]	1837–50[b]	1800–50[a]	1850–1900[c]
	(1)	(2)	(3)	(4)
OLS: Annual Population Growth Rates and Railway Access				
Rail Access 1847–64	0.03	−0.11	0.00	0.56***
	(0.04)	(0.07)	(0.04)	(0.06)
R^2	0.21	0.10	0.26	0.29
Observations	903	903	903	900
IV, Second Stage: Annual Population Growth Rates and Railway Access				
Rail Access 1847–64	0.13	0.24	0.15	0.95***
	(0.17)	(0.30)	(0.15)	(0.24)
Observations	903	903	903	900
IV, First Stage: Actual Railway Access 1847–64 and Least-Cost Paths				
LCC 1847–64	0.25***	0.25***	0.25***	0.25***
	(0.04)	(0.04)	(0.04)	(0.04)
R^2	0.29	0.29	0.29	0.29
Observations	903	903	903	900

Notes: The dependent variable is annual population growth in percent. The controls used are distance to the nearest city (log), distance to the nearest Stephenson-Swinburne node (log), subsequent railway access (binary), access to main road (binary), access to navigable water (binary), elevation (log), water power potential (binary), town privilege (binary), area in km^2 (log), and cantonal fixed effects. Additional controls, ***a***: population in 1800 (log); ***b***: population in 1837 (log); ***c***: population in 1850 (log) and annual population growth 1800–1850. ***Sample:*** Municipalities for which population data is available for the pre-railway period (four cantons: ZH, BE, SO, AG), excluding nodes and municipalities strongly affected by railway construction work (source: Rey, 2003, 147-149). The instrument is based on a least-cost path for railway lines between the 20 largest cities and Stephenson-Swinburne nodes. Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

Table B.5: The Impact of Railway Access (1847–64) on Annual Population Growth Rates, Cross-Sectional Estimates (Sample: Municipalities with Pre-Railway Data Available and Mean District Elevation below 1 000 m.a.s.l.)

	Pre-Treatment			Post-Treatment
	1800–37[a]	1837–50[b]	1800–50[a]	1850–1900[c]
	(1)	(2)	(3)	(4)
OLS: Annual Population Growth Rates and Railway Access				
Rail Access 1847–64	0.02	−0.13+	−0.02	0.54***
	(0.04)	(0.08)	(0.04)	(0.06)
R^2	0.22	0.11	0.27	0.29
Observations	826	826	826	826
IV, Second Stage: Annual Population Growth Rates and Railway Access				
Rail Access 1847–64	0.08	0.28	0.13	0.88***
	(0.18)	(0.32)	(0.16)	(0.26)
Observations	826	826	826	826
IV, First Stage: Actual Railway Access 1847–64 and Least-Cost Paths				
LCC 1847–64	0.24***	0.24***	0.24***	0.24***
	(0.05)	(0.05)	(0.05)	(0.05)
R^2	0.29	0.29	0.29	0.29
Observations	826	826	826	826

Notes: The dependent variable is annual population growth in percent. The controls used are distance to the nearest city (log), distance to the nearest Stephenson-Swinburne node (log), subsequent railway access (binary), access to main road (binary), access to navigable water (binary), elevation (log), water power potential (binary), town privilege (binary), area in km^2 (log), and cantonal fixed effects. Additional controls, ***a***: population in 1800 (log); ***b***: population in 1837 (log); ***c***: population in 1850 (log) and annual population growth 1800–1850. ***Sample:*** Municipalities for which population data is available for the pre-railway period (four cantons: ZH, BE, SO, AG) and with mean district elevation below 1 000 m.a.s.l., excluding nodes and municipalities strongly affected by railway construction work (source: Rey, 2003, 147-149). The instrument is based on a least-cost path for railway lines between the 20 largest cities and Stephenson-Swinburne nodes. Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

Table B.6: The Impact of Railway Access (1847–64) on Annual Population Growth Rates, Cross-Sectional Estimates (Sample: Municipalities with Pre-Railway Data Available)

	Long Run		10 Year Periods				
	1800–50^a	1850–1900	1850–60	1860–70	1870–80	1880–90	1890–1900
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
OLS: Annual Population Growth Rates and Railway Access							
Rail Access 1847–64	0.00	0.56***	0.24**	0.43***	0.51***	0.42***	0.76***
	(0.04)	(0.06)	(0.09)	(0.11)	(0.09)	(0.10)	(0.12)
R^2	0.26	0.29	0.07	0.11	0.18	0.14	0.17
Observations	903	900	903	903	898	898	900
IV, Second Stage: Annual Population Growth Rates and Railway Access							
Rail Access 1847–64	0.15	0.95***	0.33	0.57*	0.70+	0.68+	1.28**
	(0.15)	(0.24)	(0.28)	(0.26)	(0.36)	(0.35)	(0.49)
Observations	903	900	903	903	898	898	900
IV, First Stage: Actual Railway Access 1847–64 and Least-Cost Paths							
LCC 1847–64	0.25***	0.25***	0.33***	0.33***	0.27***	0.27***	0.25***
	(0.04)	(0.04)	(0.05)	(0.05)	(0.05)	(0.05)	(0.04)
R^2	0.29	0.29	0.21	0.22	0.26	0.27	0.29
Observations	903	900	903	903	898	898	900

Notes: The dependent variable is annual population growth in percent. The controls used are distance to the nearest city (log), distance to the nearest Stephenson-Swinburne node (log), subsequent railway access (binary), access to main road (binary), access to navigable water (binary), elevation (log), water power potential (binary), town privilege (binary), population in 1850 (log), area in km^2 (log), population in 1850 (log), annual population growth 1800–1850, and cantonal fixed effects. Other controls, ***a***: population in 1800 (log) instead of 1850, and without annual population growth 1800-1850. ***Sample:*** Excluding nodes and municipalities strongly affected by railway construction work (source: Rey, 2003, 147-149). The instrument is based on a least-cost path for railway lines between the 20 largest cities and Stephenson-Swinburne nodes. Huber-White standard errors in parentheses.. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

Table B.7: The Impact of Railway Access (1847–64) on Annual Population Growth Rates, Cross-Sectional Estimates, (Sample: Municipalities with Pre-Railway Data Available and Mean District Elevation below 1 000 m.a.s.l.)

	Long Run		10 Year Periods				
	1800–50^a	1850–1900	1850–60	1860–70	1870–80	1880–90	1890–1900
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
OLS: Annual Population Growth Rates and Railway Access							
Rail Access 1847–64	–0.02	0.54***	0.28**	0.43***	0.50***	0.42***	0.74***
	(0.04)	(0.06)	(0.09)	(0.11)	(0.09)	(0.10)	(0.12)
R^2	0.27	0.29	0.07	0.11	0.19	0.13	0.19
Observations	826	826	826	826	821	821	826
IV, Second Stage: Annual Population Growth Rates and Railway Access							
Rail Access 1847–64	0.13	0.88***	0.47	0.52+	0.61	0.70+	1.06*
	(0.16)	(0.26)	(0.29)	(0.27)	(0.38)	(0.37)	(0.51)
Observations	826	826	826	826	821	821	826
IV, First Stage: Actual Railway Access 1847–64 and Least-Cost Paths							
LCC 1847–64	0.24***	0.24***	0.33***	0.32***	0.26***	0.26***	0.24***
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
R^2	0.29	0.29	0.20	0.21	0.25	0.26	0.29
Observations	826	826	826	826	821	821	826

Notes: The dependent variable is annual population growth in percent. The controls used are distance to the nearest city (log), distance to the nearest Stephenson-Swinburne node (log), subsequent railway access (binary), access to main road (binary), access to navigable water (binary), elevation (log), water power potential (binary), town privilege (binary), population in 1850 (log), area in km^2 (log), population in 1850 (log), annual population growth 1800–1850, and cantonal fixed effects. Other controls, ***a***: population in 1800 (log) instead of 1850, and without annual population growth 1800–1850. ***Sample:*** Municipalities of districts with a mean elevation below 1 000 m.a.s.l., excluding nodes and municipalities strongly affected by railway construction work (see Rey, 2003, 147-149). The instrument is based on a least-cost path for railway lines between the 20 largest cities and Stephenson-Swinburne nodes. Huber-White standard errors in parentheses.. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

Additional Results: Displacement Effects and Heterogeneity

Table B.8: Distance to Railway (1847–64) and Annual Population Growth Rates, Cross-Sectional OLS Estimates at the Municipal Level

	Pre-Treatment Sample[a]			Whole Switzerland	
	1800–50	1850–70	1850–1900	1850–70	1850–1900
	(1)	(2)	(3)	(4)	(5)
Rail Access 1847–64	0.04	0.12	0.39***	0.21***	0.34***
	(0.06)	(0.11)	(0.08)	(0.06)	(0.04)
Distance to Railway 0–2 km	–0.01	–0.05	0.00	0.14+	0.16**
	(0.07)	(0.12)	(0.10)	(0.07)	(0.06)
Distance to Railway 2–4 km	0.00	–0.28**	–0.17*	–0.11*	–0.08*
	(0.05)	(0.10)	(0.07)	(0.05)	(0.04)
Distance to Railway 4–6 km	0.07	–0.26**	–0.20**	–0.15**	–0.14***
	(0.05)	(0.10)	(0.07)	(0.05)	(0.04)
Distance to Railway 6–8 km	0.11*	–0.31**	–0.26***	–0.15**	–0.19***
	(0.06)	(0.10)	(0.07)	(0.05)	(0.04)
Distance to Railway 8–10 km	0.10*	–0.13	–0.19*	0.02	–0.09*
	(0.05)	(0.12)	(0.08)	(0.06)	(0.04)
R^2	0.27	0.13	0.30	0.18	0.29
Observations	903	903	903	2810	2790

Notes: The dependent variable is annual population growth in percent. The municipalities with railway access are always excluded from the groups of distance dummies. The controls used are distance to the nearest town node (log), distance to the nearest Stephenson-Swinburne node (log), subsequent railway access (binary), access to main road (binary), access to navigable water (binary), elevation (log), water power potential (binary), town privilege (binary), population in 1850 (log), area in km^2 (log), annual district population growth 1800–1850, and cantonal fixed effects. Distance dummies are exclusive, municipalities with direct railway access are not in the group of municipalities with a distance of 0–2km. The reference group are municipalities with a distance from the railway line larger than 10 km. ***Sample:*** All municipalities of Switzerland, excluding nodes and municipalities strongly affected by railway construction work (source: Rey, 2003, 147-149). ***a***: pre-railway sample available for 4 cantons. Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

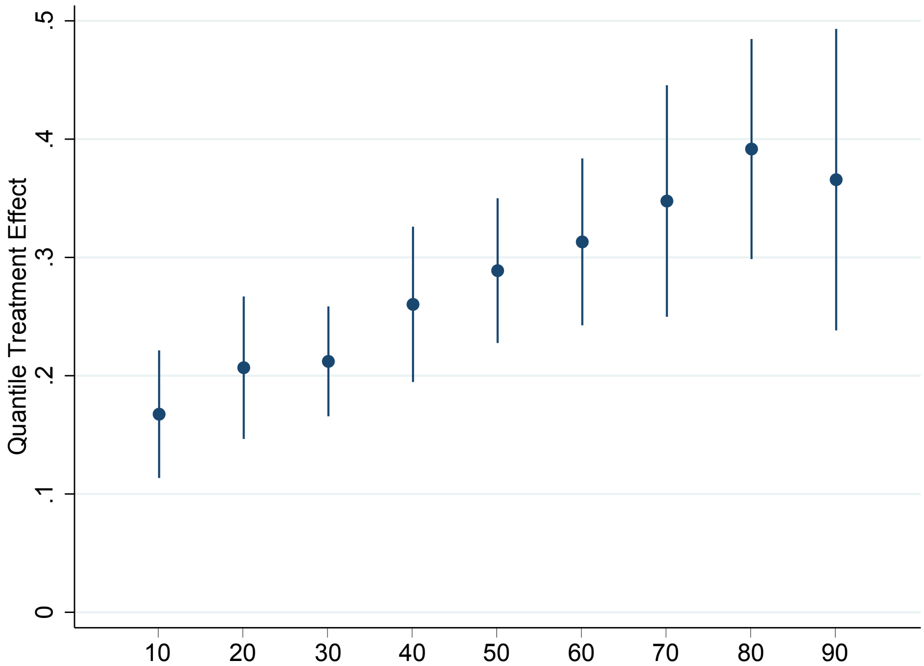


Figure B.1: Quantile Treatment Effects of Railway Access (1847–64) on Annual Population Growth (1850–1900), 10th to 90th Percentile.

Controls: Distance to the nearest town node (log), distance to the nearest Stephenson-Swinburne node (log), subsequent railway access (binary), access to main road (binary), access to navigable water (binary), elevation (log), water power potential (binary), town privilege (binary), population in 1850 (log), area in km^2 (log), annual district population growth 1800–1850, and cantonal fixed effects.

C. Empirical Appendix: District Level

Robustness: Districts with Mean Elevation below 1 000 Meters

Table C.1: The Impact of Railway Access on Annual Population Growth Rates, Cross-Sectional and Panel Estimates (Sample: Districts with a Mean Elevat. below 1 000 m.a.s.l.)

	Cross Section			Panel FE	Panel IV FE	IV FS
	1800–50	1850–1900		1850–1900	1850–1900	1850–1900
	(1)	(2)		(3)	(4)	(5)
RASHR 1847–64	−0.06	0.47^{*}	Lag RASHR	0.44^{**}	0.63^{+}	
	(0.21)	(0.18)		(0.15)	(0.39)	
RASHR 1865–82	−0.10	0.82^{***}	LCPSHR			0.48^{***}
	(0.22)	(0.21)				(0.09)
RASHR 1883–99	−0.28	0.41^{*}				
	(0.23)	(0.21)				
R^2	0.48	0.58	R^2 (within)	0.39	–	0.77
Observations	80	80	Observations	400	400	400
			Districts	80	80	80

Notes: Dependent variable is the annual population growth rate in percent. *RASHR* is defined as the share of a district's population that lives in a municipality with direct access to the railway network. The controls used are distance to the nearest node (log, population weighted), access to main road (population weighted), mean district elevation (log), population in 1850 (log), and population growth 1800–1850. The sample comprises all districts with a mean elevation below 1 000 m.a.s.l., except for districts including one of the 33 nodes, and districts strongly affected by railway construction work (source: Rey, 2003, 147-149). The instrument is based on a least-cost path for railway lines between the 20 largest cities and Stephenson-Swinburne nodes. The first stage regression is shown in the last column. *LCPSHR* is the population weighted share of municipalities in a district that lie on the least-cost path. Panel estimations include district fixed effects, year fixed effects and year-cantonal fixed effects. Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

Table C.2: The Impact of Railway Access on Migration and Birth Surplus, Cross-Sectional and Panel Estimates (Sample: Districts with a Mean Elevation below 1 000 m.a.s.l.)

	Cross Section (1870–1900)			Panel FE (1870–1900)	
	Migration[a]	Birth Surplus[b]		Migration[a]	Birth Surplus[b]
	(1)	(2)		(3)	(4)
RASHR 1847–64	16.24^{+}	1.38	Lag RASHR	4.95^{**}	1.88^{+}
	(9.06)	(1.47)		(1.85)	(0.99)
RASHR 1865–82	25.63^{**}	1.51			
	(9.17)	(1.33)			
RASHR 1883–99	17.03^{+}	−3.69			
	(8.91)	(2.93)			
R^2	0.61	0.70	R^2 (within)	0.42	0.36
Observations	72	72	Observations	215	215
			Districts	72	72

Notes: *RASHR* is defined as the share of a district's population that lives in a municipality with direct access to the railway network. Dependent variable, ***a***: A district's net balance of migration flow, indicates inflow - outflow. ***b***: A district's birth surplus as a share of average population. Railway access is measured by the share of the population that has access (municipalities with railway line) to the railway network. The sample comprises all districts with a mean elevation below 1 000 m.a.s.l., except for districts including one of the 33 main nodes, and districts strongly affected by railway construction work (source: Rey, 2003, 147-149). The controls used in the cross-section estimation are distance to the nearest city (log, population weighted), access to main road (population weighted), mean district elevation (log), population in 1850 (log), and population growth 1800–1850. Cross-section estimations include cantonal fixed effects. Panel estimations include district fixed effects, year fixed effects and year-cantonal fixed effects. Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

Table C.3: The Impact of Railway Access on Sectoral Work Shares and Body Height, Cross-Sectional Estimates (Sample: Districts with a Mean Elevation below 1 000 m.a.s.l.)

	Sectoral Shares (1860–1900)[a]				Body Height[b]
	Agriculture	Manufacturing	Services		1890–1910
	(1)	(2)	(3)		(4)
RASHR 1847–64	−16.87**	11.80*	4.67**		
	(5.73)	(5.31)	(1.66)		
RASHR 1865–82	−22.95***	18.96**	3.91*	RASHR 1847–82	0.59
	(6.14)	(5.53)	(1.58)		(0.39)
RASHR 1883–99	−12.04*	5.65	6.45***	RASHR 1882–99	1.08*
	(5.02)	(4.63)	(1.39)		(0.53)
R^2	0.62	0.65	0.47	R^2	0.77
Observations	77	77	77	Observations	79

Notes: *RASHR* is defined as the share of a district's population that lives in a municipality with direct access to the railway network. Dependent variable, ***a:*** Percentage point change in a district's sectoral work share (agriculture, manufacturing, services). ***b:*** Centimeter change in a district's conscripts average body height between 1884/91 and 1908/12. The controls used are distance to the nearest city (log, population weighted), access to main road (population weighted), mean district elevation (log), population in 1850 (log), population growth 1800–1850, and cantonal fixed effects. Additionally, models in columns ***a*** control for the district's sectoral work share in 1860 (agric., indust., services), while column ***b*** includes the district's average body height for the 1884/91 conscription. The sample comprises all districts with a mean elevation below 1 000 m.a.s.l., except for districts including one of the 33 main nodes, and districts strongly affected by railway construction work (source: Rey, 2003, 147-149). Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

Table C.4: The Impact of Railway Access on Sectoral Work Shares, Panel Estimates (Sample: Districts with a Mean Elevation below 1 000 m.a.s.l.)

	Panel FE (1860–1900)			Panel IV FE (1860–1900)		
	Agriculture	Manufact.	Services	Agriculture	Manufact.	Services
	(1)	(2)	(3)	(1)	(2)	(3)
Lag RASHR	−6.74***	7.09***	−0.35	−11.10*	8.33	2.76+
	(1.61)	(1.47)	(0.50)	(5.53)	(5.09)	(1.52)
R^2 (within)	0.62	0.57	0.61	–	–	–
Districts	77	77	77	77	77	77
Observations	357	357	357	357	357	357

Notes: *RASHR* is defined as the share of a district's population that lives in a municipality with direct access to the railway network. Dependent variable: A district's sectoral work share in percent (agriculture, manufacturing, services). The sample comprises all districts with a mean elevation below 1 000 m.a.s.l., except for districts including one of the 33 main nodes, and districts strongly affected by railway construction work (source: Rey, 2003, 147-149). The instrument is based on a least-cost path for railway lines between the 20 largest cities and Stephenson-Swinburne nodes. Panel estimations include district fixed effects, year fixed effects and year-cantonal fixed effects. Huber-White standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

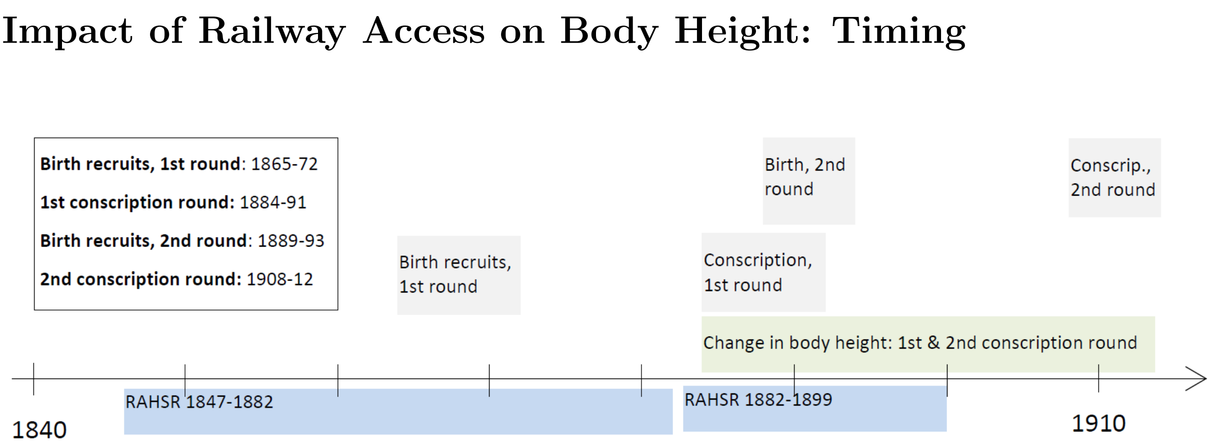


Figure C.1: Impact of Railway Access on Body Height, Timing.

3 Do Words Matter? The Impact of Communication on the PIIGS' CDS and Bond Yield Spreads during Europe's Sovereign Debt Crisis*

3.1 Introduction

The European debt crisis has sparked a heated controversy on its causes, mechanics, and potential solutions. This paper aims to contribute to the ongoing debate by focusing on an aspect that has – at least to my knowledge – not been analysed systematically so far: Communication by the eurozone's policy-makers and its effect on sovereign Credit Default Swap (CDS) and bond yield spreads.[1]

Communication can alter expectations and with it market outcomes for at least two reasons (cf. Blinder et al., 2008). In the presence of *asymmetric information* between policy-makers and the public, communication can hold important information for market participants. Furthermore, individuals may base their decisions on *heuristics*, since rational optimisation is too complex. Communication can provide the basis for such shortcuts, and thereby directly influence behaviour. Indeed, a number of empirical studies provide convincing evidence for the impact of communication by central bankers on the economy (for a comprehensive survey see Blinder et al., 2008).

Even though a substantial body of research on central bank communication has emerged, there are hardly any studies on the impact of public statements by other institutions.[2] Little is known about the effects of public statements by decision-makers beyond the field of monetary

[1] As the global financial crisis evolved into a (European) sovereign debt crisis, the developments of sovereign CDS and bond yield spreads have received heightened attention. For instance, Aizenman, Hutchison and Jinjarak (2013) investigate the main macroeconomic determinants of sovereign CDS spreads, whereas von Hagen, Schuknecht and Wolswijk (2011) study cross country differences in sovereign bond yields. Both studies find that markets have penalised fiscal imbalances more strongly after the outbreak of the financial crisis in fall 2008 than before.

[2] One exception is a paper by Burkhard and Fischer (2009). The authors compare exhange rate reactions to verbal references by the Swiss National Bank on the one hand, and calls for interventions by the IMF, OECD and Swiss government officials on the other hand. Whereas the National Bank's verbal interventions affect financial markets, Burkhard and Fischer (2009) do not find any responses to statements by the other agents considered.

*This chapter partially builds on my MA-Thesis "Putting Lipstick on the PIIGS: Does Communication Affect European CDS and Bond Yield Spreads?" and was published in the *European Journal of Political Economy*, Vol. 32 (2013) 412–431.

policy. Despite this lack of empirical knowledge, it is often argued that communication plays a crucial role in crisis management (e.g. Boin et al., 2005). Repeated calls for more verbal discipline among European officials – in some cases one could refer to open disputes – highlight the significance attributed to communication in dealing with the eurozone crisis.[3]

The question whether communication actually matters in the context of the ongoing debt crisis, however, remains unanswered. This paper argues that the eurozone's institutional framework and its strategy to manage the crisis cause great uncertainty among private agents, which is why they strongly rely on *policy signals* by leading decision-makers. Since politicians and central bankers cannot only intervene decisively in the economy, but also have superior knowledge about the tools they consider appropriate to do so, a substantial level of asymmetric information prevails. Hence, by commenting on potential policy options decision-makers can provide valuable information to market participants. More specifically, such statements can give important insights on the European community's commitment to support indebted nations and protect its creditors, which in turn can affect the behaviour of investors.

To study the impact of communication by the eurozone's leading decision-makers, I examine the sovereign CDS and bond yield spreads of the so-called PIIGS, namely Portugal, Ireland, Italy, Greece, and Spain. I thereby draw on daily data for the period between January 1, 2009 to August 12, 2011 which I analyse in an EGARCH framework. The results suggest that both hawkish and dovish statements moved financial markets during the period under consideration. Dovish comments display a weaker pattern with respect to sign and significance than hawkish statements, especially in the bond yield models, which seem to be less responsive than CDS premia.

The paper starts by discussing the role of communication in the context of the European debt crisis. Section 3.3 presents the data. Section 3.3.3 discusses the results of the main empirical analysis and tests for robustness. Section 3.4 concludes.

3.2 The Role of Communication in Europe's Crisis Management

Rating downgrades of Portugal, Spain, Greece, and Ireland in early 2009 sparked growing concerns about the sustainability of public finances within the eurozone. As the situation deteri-

[3]For instance, ECB executive board member Lorenzo Bini Smaghi accused Germany for driving up the bailout costs, stating that "[i]n one large euro area country it was thought that public support for swift action could be achieved by dramatizing the situation. But it was not realized that, in the mist of financial upheaval, such words are like fanning the flames [...]" (Dow Jones, 28/05/2010). At the same time, the ECB was also critised for its communication strategy. Whereas Jean-Claude Juncker pledged the Central Bank to "speak with one voice" (Reuters, 01/11/2010), Chicago economist Harald Uhlig accused its President to have "ruined the reputation of the ECB" due to the "worst communication from a central banker" that he had ever seen (Market News International, 01/06/2010). Some statements even triggered disputes among cabinet colleagues. In September 2011, Philipp Rösler, Germany's minister of economics and technology, commented on scenarios for a Greek insolvency. In response, Wolfgang Schäuble publicly rebuked him, pointing out that all matters related to the Euro are part of the finance ministry's responsibility. Voicing his resentment, Schäuble added: "I can't help it that others comment on these issues as well." See *Süddeutsche Zeitung:* "Offener Streit um Griechenland-Äusserungen." First published on September 17, 2011. Online available: `http://www.sueddeutsche.de/politik/schaeuble-gegen-roesler-der-finanzminister-ist-fuer-den-euro-zustaendig-1.1145200`.

orated further, numerous economists and politicians even questioned the survival of Europe's common currency. In handling these serious developments, communication could have played a decisive role for at least three reasons.

First, the eurozone's institutional framework provides little detail regarding tools for the management of a debt crisis. The 'no-bailout clause' was formerly interpreted as ruling out any bilateral or coordinated financial aid within the common currency area. Besides, neither the Maastricht Treaty nor its amendments provide a legal basis for an orderly sovereign default procedure or a member state expulsion.[4] Complicating things further, the eurozone's multilayer decision-making process is prone to deadlocks because many rulings require unanimity. In this context, politicians and central bankers were forced to formulate a crisis strategy from scratch, and markets could only rely on their verbal references to anticipate potential interventions within the common currency area.

Second, eurozone officials have been gradually taking countermeasures thereby leaving room for continuous adjustments. Once it had become clear that Europe's policy-makers were willing to circumvent the no-bailout clause their further intentions regarding private sector involvements, the EFSF's lending power, exits and expulsions of member states, the ECB's collateral framework and sovereign bond buys have remained somewhat opaque. Therefore, statements on future policy decisions may have decisively shaped the market's perception of the EMU's long-term commitment to support heavily indebted countries. Given that the pricing of the PIIGS' market debt crucially depends on the credibility of this commitment (cf. Arghyrou and Tsoukalas, 2011), communication could substantially influence market outcomes.

Third, the eurozone's institutional setup may decisively amplify the effects of verbal interventions: Comparing developments in Spain and the United Kingdom, Kopf (2011) and De Grauwe (2011) outline how the eurozone can give rise to *self-fulfilling prophecies* that would not occur in countries controlling their own currency. In this respect, communication may have the potential to shift expectations such that a stabilising dynamic with falling interest rates, or, on the contrary, a vicious circle with steeply rising debt costs is initiated.

Having argued that communication may indeed matter, the importance of a statement's focus needs to be briefly discussed. One can distinguish between general communication and talk directed towards a specific country, for instance Greece. If communication has an impact one would assume that both types of statements affect the price of Greek sovereign debt. But what about the spreads of other peripheral countries, like Portugal, Ireland, Italy, or Spain? General statements clearly address these countries as well, therefore one would expect a similar impact as in the case of Greece. Furthermore, it seems reasonable to assume that country specific communication unfolds not only a direct impact but also affects other EMU member states facing comparable challenges, since such messages are indicative for the eurozone's general commitment to support indebted countries. A recent study by Mink and De Haan (2012)

[4] Athanassiou (2009) examines the issue of secession and expulsion from the EU and Eurozone. While an expulsion of a member is not possible, a country's unilateral withdrawal would be feasible. According to the author, such a decision would necessarily involve a parallel exit from the EU.

Table 3.1: The Decision-Makers Considered in the Analysis

Institution	Position	Name
European Central Bank	President	J.-C. Trichet
	Exec.Board Members	V. Constancio (∼06/10: L. Papademos), L. Bini Smaghi, J. Stark, P. Praet (∼05/11: G. Tumpel-Gugerell), J. Páramo
	National Governors	E. Nowotny, G. Quaden, A. Orphanides, E. Liikanen, C. Noyer, J. Weidmann (∼04/11: A. Weber), G. Provopoulos, P. Honohan, (∼09/09: J. Hurley), M. Draghi, Y. Mersch, J. Bonnici, (∼07/11: M. Bonello), K. Knot (∼07/11: N. Wellink), C. Costa (∼05/10: V. Constancio), J. Makúch (∼12/09: I. Sramko), M. Kranjec, M. Ordonez.
EU officials		
Commission	President	J. Barroso
	Financial Affairs	O. Rehn (∼02/10: J. Almunia)
European Council	President	H. Van Rompuy
Euro Group	President	J.-C. Juncker
National Representatives		
France	President	N. Sarkozy
	Minister of Finance	F. Baroin (∼6/2011: C. Lagarde)
Germany	Chancellor	A. Merkel
	Minister of Finance	W. Schäuble (∼10/2009: P. Steinbrück)
Portugal, Ireland, Italy, Greece, Spain	Head of Government	G. Papandreou (∼10/09: K. Karamnlis), E. Kenny (∼03/11: B. Cowen), S. Berlusconi, P. Coelho (∼06/11: J. Sócrates), L. Zapatero
	Ministers of Finance	E. Venizelos (∼06/11: G. Papakonstantinou, ∼10/09: K. Karamanlis), M. Noonan (∼03/11: B. Lenihan), G. Tremonti, V. Gaspar (∼06/11: F. d. Santos), E. Salgado (∼04/09: P. Solbes)
Other Eurozone Members	Head of Government	W. Faymann, Y. Leterme (∼11/09: H. Van Rompuy), D. Christofias, J. Katainen (∼06/11: M. Kiviniemi, ∼06/10: M. Vanhanen), J.-C. Juncker[a], L. Gonzi, M. Rutte (∼10/10: J. Balkenende), I. Radicová (∼10/10: R. Fico)
	Ministers of Finance	M. Fekter (∼04/11: J. Pröll), D. Reynders, C. Stavrakis, J. Urpilainen (∼06/11: J. Katainen), L. Frieden (∼07/09:J.-C. Juncker), T. Fenech, J. de Jager (∼02/10: W. Bos), I. Miklos (∼07/10: J. Pociatek), F. Krizanic

Note: Names of the office holders in August 2011. For the period of interest, their predecessors as well as the date of their resignation are listed in brackets. **a** Statements by J.-C. Juncker are attributed to his role as Eurogroup head.

provides some support for this view: The authors show that news about a Greek bailout also lead to abnormal returns on the bond prices of other peripheral eurozone countries suggesting that policy signals for one specific member state also serve as a landmark in the assessment of other troubled eurozone countries.

Finally, it needs to be determined, whose statements may have an impact on financial markets. As pointed out, a vast number of policy-makers play a decisive role in the EMU's transnational decision-making process. This study attempts to analyse the effects of communication for the key players only. In the following, I briefly motivate my selection as presented in Table 3.1.

As the Euro's guardian, the ECB undoubtedly plays a key role in economic crisis management. Therefore, the analysis covers communication by all Governing Council Members who form the Central Bank's main decision-body.

With the exception of matters directly linked to monetary policy, national representatives take the centre stage in crisis management. Ultimately, all landmark decisions have to be adopted at the national level. Although each eurozone member had to approve the rescue measures currently in place, it is evident that the two largest nations, namely Germany and France, took the leadership in the EMU's crisis management. Among national politicians, the head of government and the finance minister are of particular importance, because they represent their country as chief negotiators in economic and financial matters on the European level.

Even though arguably less influential than France and Germany, representatives of the other eurozone member countries are included in the study as well. As their statements are covered with lower frequency in newswire reports, they are not analysed individually but divided into two groups, namely the PIIGS countries and the remaining members states respectively.[5]

Finally, a small number of EU officials is considered as well, since they undertake various important tasks such as coordinating the decision-making process or (unofficially) representing the EMU. The analysis includes communication by the heads of the European Commission, the European Council and the Euro Group as well as statements by the Commissioner for Economic and Financial Affairs.

3.3 Data and Descriptive Analysis

In order to examine the effect of communication on sovereign CDS and bond yield spreads, data for the period between January 1, 2009 and August 12, 2011 is analysed. Baldwin (2011) refers to this period as *phase one* of the debt crisis: In January 2009, Standard & Poor's lowered the long-term credit ratings of Greece, Spain, and Portugal sparking discussions about the sustainability of public finances in the eurozone. Prior to that, top European officials paid hardly any attention to this issue or at least did not comment on it publicly. In August 2011, it became apparent that contagion reached the core of the eurozone heralding the debt crisis' second phase.

The Euro-denominated sovereign CDS and bond yield data, recorded daily at 18:00 CET, was obtained from Thomson Reuters Datastream. The CDS premia are based on mid bid-ask spreads, whereas the bond yields rest upon bid prices. For both securities, various maturities including 5 years, 10 years, and 30 years are analysed. The analysis on CDS premia also covers data on contracts with 1 year maturity which was not available for government bonds. Both CDS and bond yield spreads are calculated vis-à-vis the analogous German securities.[6]

Although the paper's statistical approach is somewhat different than the event study methodology outlined in MacKinlay (1997), the underlying idea is similar: If an event, i.e. a public statement by a top official, affects financial markets, an immediate asset price reaction should be observable. Assuming that one can precisely identify the occurrence of events, it is possible to minimise confounding effects by narrowing the reaction window. A narrow reaction window also supports the assumption that communication is contemporaneously exogenous, i.e. $E(\epsilon_t|x_t) = 0$, which is needed to establish consistency of the coefficients' estimates. I compare changes in spreads on days without communication to changes in spreads on days with relevant statements, thereby comments outside trading hours, i.e. after 18:00 CET or at weekends, are assumed to affect financial markets on the following trading day. The use of daily financial data and newswire reports with time stamps allow for this procedure.

[5]These are Austria, Belgium, Cyprus, Finland, Luxembourg, Malta, Netherlands, Slovakia and Slovenia. Until January 2011 Estonia was not a member of the eurozone and is therefore excluded.

[6]The use of spreads vis-à-vis a comparable risk free security is a common approach in the event study methodology, if the construction of abnormal returns based on the differences between model-generated and actual movements in the dependent variable is not possible (eg. Afonso, Furceri and Gomes, 2012). One issue is that the benchmark security itself may be affected by communication. This aspect receives further attention in section 3.3.5.

3.3.1 Measuring Communication

Eurozone leaders need to engineer and agree on appropriate countermeasures which potentially take many forms. Communication is therefore not restricted to a well-known set of tools but has a fairly wide scope with changing focuses. The following passages give an outline of the study's approach to create a valid measure of communication taking these complications into account.

In a first step, all relevant statements had to be gathered. To this end, I drew on Factiva, a newswire database by Dow Jones. I scanned the Factiva database using a broad set of search terms composed of <THE DECISION-MAKER'S LAST NAME> AND <A CRISIS RELATED KEY WORD>.[7] The set of eurozone officials considered is equivalent to Table 3.1 and a list of key words used to scan the database is presented in the appendix (see Table A.1). Due to the limited number of statements, all types of communication such as interviews, speeches, official statements etc. are taken into account.

Three caveats specifically related to the use of newswire reports should be emphasized (cf. Ehrmann and Fratzscher, 2007; Jansen and De Haan, 2006). First, newswire services are selective in their reporting. As I am interested in testing the market response to communication, however, it makes sense to focus only on those comments that actually reach market participants. This is best achieved by relying on prominent newswire agencies.[8] Second, newswire services might wrongly report or misinterpret a statement by policy makers. Again, one can argue that the objective is to analyse the effect of communication as received by the markets. Moreover, the vast majority of newswire reports include direct quotes, which allow the researcher and the market participants to evaluate the content of a decision-maker's statement without relying on the news agency's interpretation. Third, as the choice of search terms is restricted, some relevant statements might be filtered out. Besides, the inclusion of rather general keywords, for instance <GREECE>, inflates the output of newswire reports, which again have to be screened with respect to their relevance by the researcher. This might lead to the omission of relevant statements. However, since prominent and highly visible messages should have both a higher probability to affect financial markets and a higher probability to be selected in the filtering process, the confounding effects of omitted statements should be rather low.

Following the collection of relevant newswire reports, their content had to quantified. To ensure a high degree of objectivity, I applied the content-analysis technique outlined by Merten (1995). In a first step, a randomly chosen subset of newswire reports across the entire time range was utilised to construct a codebook. It specifies coding-instructions, that enable a quantification of the communication's content in the most consistent manner possible. In particular, the codebook defines for various subject specific categories when the content of a statement can be interpreted as a *dovish policy signal*, i.e. high commitment to protect private investors, or as a *hawkish policy signal*, i.e. low commitment to shield creditors. The second step included

[7]The scan was restricted to the headline and first paragraph, so that only newswire reports focusing on the relevant information were selected.

[8]The search was limited to major news agencies, including Reuters, Dow Jones Newswires, Agence France-Press (AFP), Associated Press Newswires (AP), and Market News International (MNI).

a quantification of each newswire report. Thereby, great attention was paid to distinguish between the first report and its replications on subsequent days, so that double-coding of the same information could be avoided. If the codebook did not provide a clear coding rule for a statement, it was indicated accordingly. Lastly, all statements labelled as ambiguous were reassessed. If it was not possible to derive an adequate quantification, the statement was dropped from the dataset.

Finally, I constructed binary communication variables which cover either dovish or hawkish statements on A) financial aid to the PIIGS, B) size of the financial safety net, C) expulsion of EMU members, D) sovereign default scenarios or an enforced private sector involvement, and E) voluntary contributions by private creditors.[9] Regarding communication by central bank officials, the indices are supplemented by the categories F) changes in the ECB's collateral framework and G) government bond purchases on the secondary market. These variables do not capture whether it was a general or a country-specific statement. As argued in section 3.2, this can be justified on the grounds that the EMU's handling of the problem in a specific member state can set a precedent for other countries facing similar circumstances.

If the dummy covering dovish statements takes the value 1 this indicates high commitment by the policy-maker to support countries in financial difficulties and therewith protect creditors. For the dummy comprising hawkish messages a coding of 1 implies that the decision-maker shows limited commitment to guarantee the fiscal integrity of all eurozone member states. On days without communication, both binary variables take the value 0. If a policy maker made dovish and hawkish statements across the various dimensions considered, both dummies are coded 1. Further information on the seven dimensions included in the communication indices along examples of hawkish and dovish statements are provided in the appendix (Table A.1).

Based on these communication variables, Table 3.2 shows the distribution of days with verbal policy signals by ECB officials, leading EU officials and national representatives. It reveals that two aspects dominated the debate: In the early phase of the crisis, the question whether troubled

[9] Whereas the classification of statements rejecting voluntary contributions is clear-cut, the coding of its 'hawkish' analogue is somewhat ambiguous: At the outset of the crisis, there was a broad agreement among Europe's decision-makers that one needs to prevent any damage to private holders of sovereign debt. Basically, any form of private sector involvement was categorically rejected. Against this background, recurring requests for 'voluntary' private contributions may be understood as a weakening of the previous stance, which is why statements in support of voluntary participation by private investors could be classified as *hawkish*. A more contextual appraisal would rather suggest to rate such comments as *dovish*: In spring 2011, when schemes for organised voluntary contributions, e.g. the *Vienna Initiative*, were brought up in the debate, several policy-makers made clear that another Greek bailout without private sector involvement was no longer an option. In this context, voluntary contributions cannot be seen as an accentuation of the situation for private bondholders, but rather as a 'soft' version of the inevitable 'hard' restructuring of Greek debts. Furthermore, the debate on voluntary contributions signalled a compromise between the 'Hawks' and the 'Doves' preventing a deadlock in EMU's crisis management. I apply the latter (i.e. dovish) coding for two reasons. First, it seems to fit the interpretation of market analysts better. For instance, on June 17 2012, Angela Merkel signalled that she is willing to pursue private sector contributions on a mere voluntary basis. This was appreciated by market analysts who commented that "Merkel's acceptance of the Vienna initiative is somewhat of a climb down and we are moving closer to something more concrete" (A. Schmidt, Lloyds, quoted by Reuters 17/06/2011). Second, a look at the data reveals that statements supporting voluntary contributions are associated with declining spreads. The low number of such statements guarantees that this partly data driven decision has only a small impact on the results. The robustness check in section 3.3.5 also addresses this matter.

Table 3.2: Frequency of Days with Communication: Jan. 01 2009 – Aug. 12 2011

		A)	B)	C)	D)	E)	F)	G)	*A)-E)*[a]	*F)-G)*[a]
Germany	Dovish	25	0	8	14	0	-	-	*44*	-
	Hawkish	12	8	5	25	10	-	-	*49*	-
France	Dovish	23	2	1	20	0	-	-	*45*	-
	Hawkish	1	2	0	3	5	-	-	*6*	-
Portugal, Ireland	Dovish	23	2	5	21	0	-	-	*47*	-
Italy, Greece, Spain	Hawkish	3	1	0	0	1	-	-	*4*	-
Other Eurozone	Dovish	18	3	3	10	0	-	-	*34*	-
Members	Hawkish	16	7	3	24	5	-	-	*41*	-
EU officials	Dovish	46	7	12	50	2	-	-	*93*	-
	Hawkish	6	3	0	6	6	-	-	*15*	-
ECB	Dovish	21	10	33	85	6	8	20	*123*	*28*
	Hawkish	11	2	1	20	11	18	22	*32*	*35*
Total		*205*	*47*	*71*	*278*	*46*	*26*	*42*	*533*	*63*

a: A) financial aid, B) size of EFSF, C) expulsion/exit of members, D) private sector involvement, E) voluntary private sector involvement, F) collateral framework, G) bond purchases. The last columns give the total number of days with dovish and hawkish statements. Since communication may cover multiple dimensions, the numbers are not equal to the line total. Statements supporting voluntary private sector contributions (column *E*, row *hawkish*) are coded as dovish signal.

countries should be granted financial aid (category A) was at the centre of debate, whereas since May 2010 the discussion about the involvement of private creditors received most attention (category D). Thereby, not all groups of policy-makers advanced the same view. Whereas the EU officials and representatives of France predominantly signalled high commitment to shield peripheral countries, especially Germany and some of the smaller eurozone members took a fairly tough stance. Regarding communication by ECB officials, one can see a gap between 'political issues' (categories A–E) and 'ECB specific matters' (categories F–G). In the former case, the vast majority of statements can be classified as dovish, whereas comments on the two monetary policy instruments were far more disputed. Since the number of statements within the specific categories is rather low and the study focuses on the effects of communication in general, only the overall measures of communication (cf. the two last columns in Table 3.2) are analysed in detail. Thereby, hawkish comments by EU officials, French representatives, and politicians of the PIIGS countries are excluded, as such statements occurred with a too low frequency.

3.3.2 Preliminary Insights: Communication and the PIIGS-Bund Spread

In order to get a picture of the main variables analysed in this study, I briefly discuss Figure 3.1 which plots the communication variables along with the unweighted average CDS spread between Germany's Bund and the PIIGS. As the graphical representation reveals, the intensity of communication increased progressively over the considered period. In 2009, eurozone officials barely commented on how to deal with the looming European debt crisis except for two short periods early and late in the year. The level of communication reached a first peak in spring 2010, as the danger of a Greek default could no longer be denied and potential countermeasures were discussed. After a calm episode following the launch of the EFSF in May 2010, communication by European policy-makers again intensified in October. It culminated in early summer 2011, when the terms for further financial aid to Greece were discussed. In this period, spreads between Germany's and the PIIGS' CDS premia temporarily doubled, and then sharply decreased on July 21/22, when eurozone leaders reached agreement on the second rescue package for Greece. Similar turmoils on the sovereign bond and CDS market can be located in spring 2010, before the European community announced the formation of its 750 billion Euros safety net.

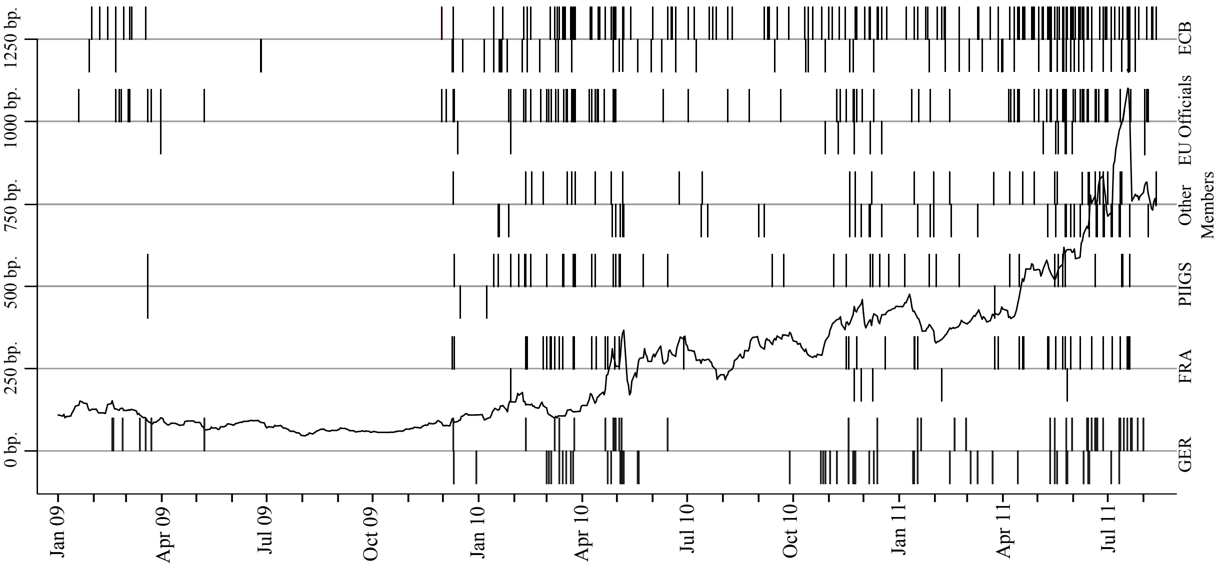


Figure 3.1: Average PIIGS-German CDS Spread and Communication by ECB Board Members, EU Officials, and National Representatives

Notes: The PIIGS-German spread is based on the PIIGS' unweighted average CDS premia with 5 years maturity. Upward bars indicate dovish statements, downward bars indicate hawkish statements.

Let us now turn to some descriptive statistics characterising the relationship between communication and the development of spreads. Table A.2 in the appendix lists the average changes in CDS and bond yield spreads distinguishing between days with hawkish comments, days with dovish statements, and days without communication.

This mere comparison of averages can be refined by limiting the analysis to narrow pre- and post-event windows. In a next step, I analyse financial market movements using a two-day window definition, which means that the spread change on a day with communication is compared to the spread change on the most recent day without such a verbal intervention, i.e. in general the previous day.[10] Besides comparing the average changes on pre- and post-event days, it is also useful to analyse the rate of 'success' of an event. One potential definition for a success is the *smoothing criterion* (see for example Fatum and Hutchison, 2003). According to the smoothing criterion, a communication-event can be classified as a success in the context of this study if

$$\Delta s_{i+} \; < \; \Delta s_{i-} \text{ for } \textit{dovish statements} \quad \text{or} \quad \Delta s_{i+} \; > \; \Delta s_{i-} \text{ for } \textit{hawkish statements}$$

where Δs_{i+} is the CDS or bond yield spread change on the event day and Δs_{i-} is the respective spread change on the associated pre-event day.[11]

The graphs in Figure 3.2 summarize the results of the analysis outlined above. On the one

[10]If one group of decision-makers made dovish (or hawkish) comments on several consecutive days (eg. t_1, t_2,

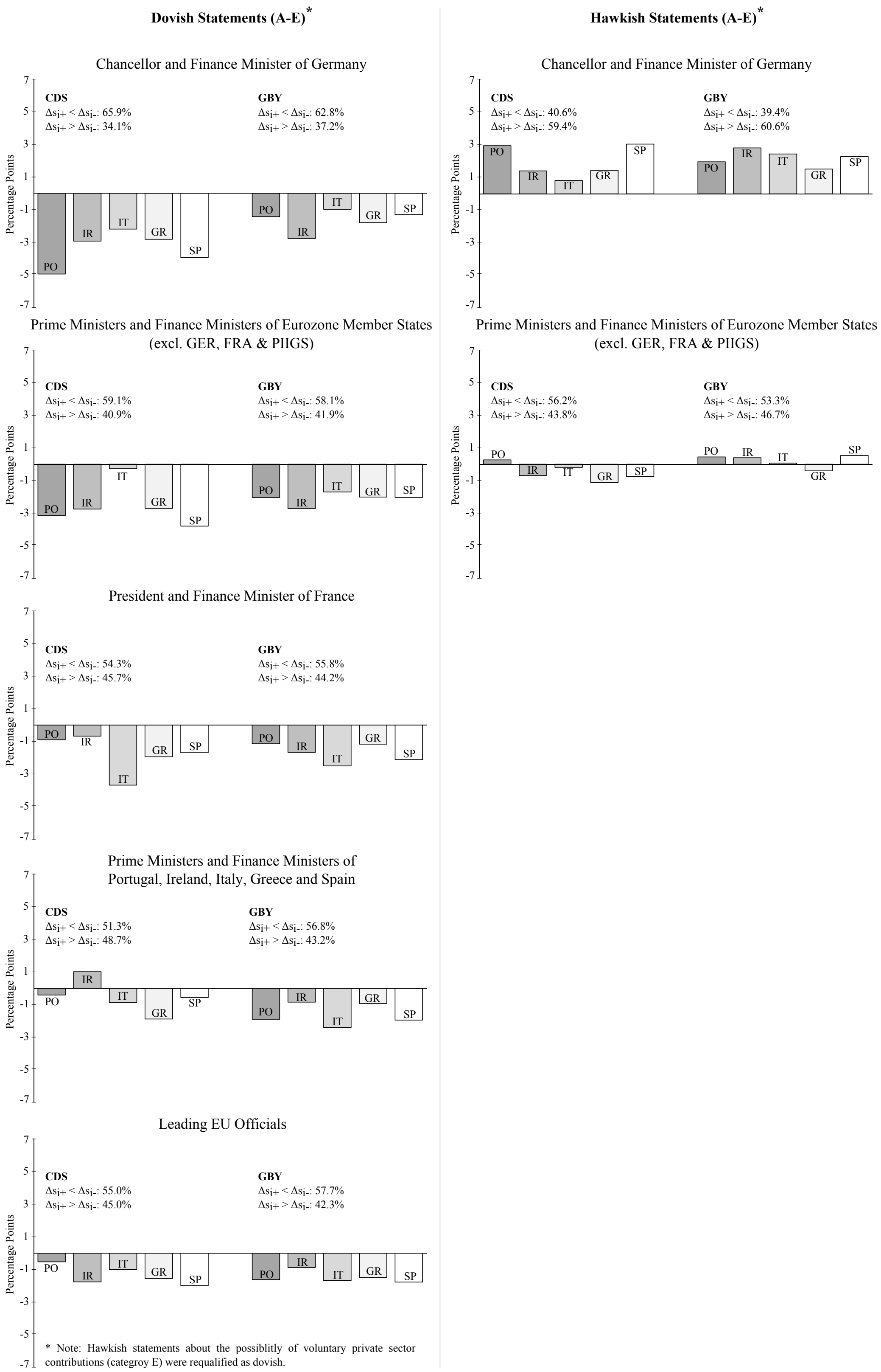


Figure 3.2: A Comparison of CDS and Bond Yield Spread Changes on Days with and without Communication, Two-Day Event Window

Notes: The CDS and bond yield spreads are computed based on an unweighted average across the four maturities considered.

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t_3), spread changes on these days are compared to the most recent day without such a statement (eg. t_0).

[11]This definition is stricter than the original formulation of the smoothing criterion. The specification applied in this study accounts for the possibility of 'leaning with the wind' communication, i.e. dovish statements during a period with declining spreads or hawkish comments during a period with raising spreads (cf. Fatum and Hutchison, 2003, p. 398).

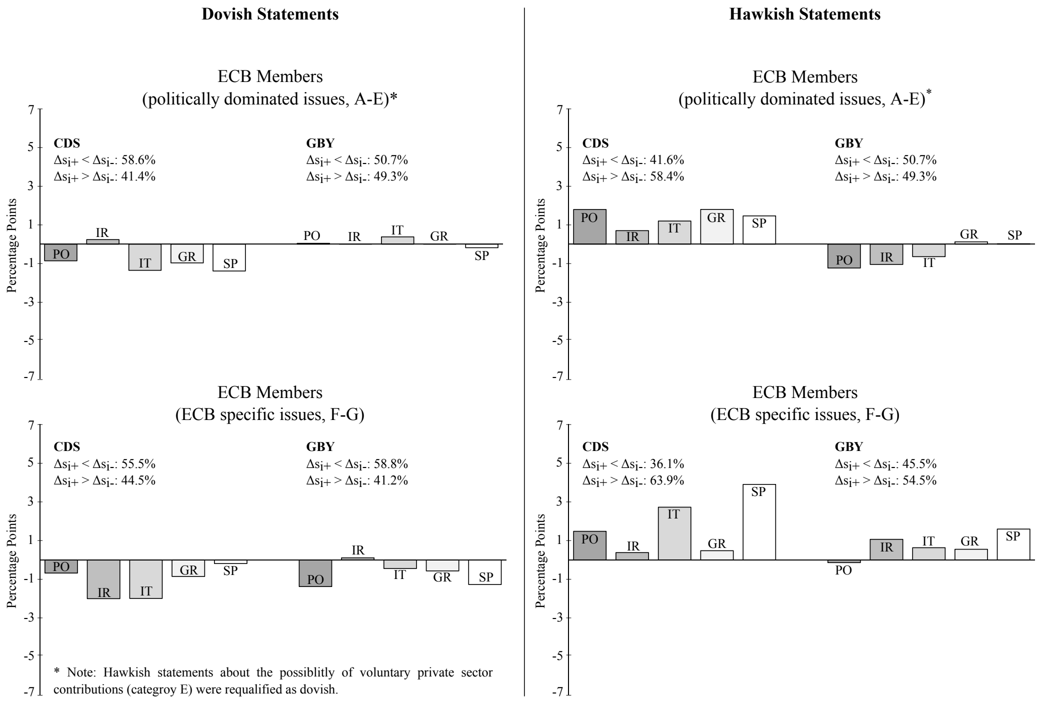

Figure 2 Continued: A Comparison of Average CDS and Bond Yield Spread Changes on Days with and without Communication, Two-Day Event Window
Notes: The CDS and bond yield spreads are computed based on an unweighted average across the four maturities considered.

hand, they suggest that on days with dovish communication spreads of peripheral eurozone countries decreased faster / increased slower than in the pre-event period. On the other hand, days with hawkish communication were associated with a faster increase / slower decrease in CDS and bond yield spreads. Thereby, the relationship between communication of German decision-makers and daily changes of CDS and bond yield spreads seems to be the strongest. The average difference between the spread change on an event day and the spread change on the respective pre-event period varies between 1 and 5 percentage points for dovish statements and 1 to 3 percentage points for hawkish statements. At the same time, the rate of success across the five peripheral eurozone states and various maturities adds up to about 60 percent. Although not as strong as in the case of Germany, Figure 3.2 reveals a similar pattern for dovish statements by French politicians, EU officials as well as leaders of smaller eurozone member states and the PIIGS countries. In contrast, the results are less clear-cut for hawkish statements by politicians of smaller eurozone countries, as well as for communication by ECB officials. In the latter case, however, the results seem to depend somewhat on the distinction between politically dominated issues (categories A–E) and ECB specific issues (categories F–G). Whereas the relationship between spread changes and communication is weak or inconsistent regarding statements on political matters, it is slightly stronger if one considers comments on government bond purchases or the collateral framework only.

It has to be noted that communication events may overlap, since statements by the five different groups of policy-makers are analysed separately. Nevertheless, this representation gives a first impression on the relation between communication and spread movements. The multivariate analysis in the subsequent section addresses the remaining issues, namely overlapping of verbal interventions and inference.

3.3.3 Multivariate Analysis

Before presenting the results of the multivariate analysis, the statistical method is briefly introduced. In examining the impact of statements by policy-makers I follow studies on central bank communication by Ehrmann and Fratzscher (2007, 2009) and use the EGARCH framework as proposed by Nelson (1991). This approach has the advantage that it corrects for the serial correlation, skewness, and time-varying volatility of CDS and bond yield spreads. Due to the leptokurtic distribution of the dependent variables, I choose a *General Error Distribution* (GED) specification. The EGARCH (1,1) model, which is estimated separately for each country and asset, formulates the conditional mean equation for relative changes in spreads s_t as

$$s_t = \alpha \; + \; \sum_k \beta^k_{DV} CMDV^k_t + \; \sum_l \beta^l_{HW} CMHW^l_t \; + \; \phi X_t \; + \; \sum_{i=1}^{max.4} \gamma_i s_{t-i} \; + \; \delta D^{4Nov09}_t \; + \; \epsilon_t. \quad (3.1)$$

CMDV^k_t and CMHW^l_t represent dummies for dovish and hawkish comments respectively, whereby k and l indicate the source and type of communication, i.e. k $\in$ {ECB (A–E), ECB (F–G), EU officials, Germany, France, PIIGS, other eurozone members} and l $\in$ {ECB (A–E), ECB (F–G), Germany, other eurozone members}. This specification enables a comparison between dovish and hawkish statements and thus allows for a detailed assessment of communication effects. Assuming that dovish statements lower spreads whereas hawkish comments raise them, we would expect that $\beta^k_{DV} \leq 0$ and $\beta^l_{HW} \geq 0$. X_t denotes a vector of controls compromising a measure for macroeconomic surprises, two variables accounting for policy decisions on the European[12] and national level, as well as two indicators for long-term credit downgrades by Standard & Poor's, Fitch and Moody's. D^{4Nov09}_t is a binary variable coded one for the period between January 1, 2009 and November 4, 2009. This dummy should account for the apparent structural change in spread movements after Greece irrevocably sparked the escalation of the debt crisis by revising its budget deficit from about 6 to 12 percent of GDP. Table A.3 in the appendix provides further detail on all control variables. As I assume $\epsilon_t \sim \text{GED}(0, \sigma^2_t, \nu)$ with ν as tail thickness parameter,[13] the conditional variance can be expressed as

$$\begin{aligned} log(\sigma^2_t) = \omega \; + \; \theta_1 \left(\left| \frac{\epsilon_{t-1}}{\sigma_{t-1}} \right| \right) \; + \; \theta_2 \left(\frac{\epsilon_{t-1}}{\sigma_{t-1}} \right) \; + \; \theta_3 log(\sigma^2_{t-1}) \; + \; \kappa D X_t \\ + \; \sum_k \tau^k_{DV} CMDV^k_t \; + \; \sum_l \tau^l_{HW} CMHW^l_t \; + \; \psi D^{4Nov09}_t. \end{aligned} \quad (3.2)$$

[12] All statements on days with European policy decisions are excluded in the multivariate analysis. In doing so, one can guarantee that financial market reactions to major reforms are not wrongly attributed to communication. Since less than 10% of the statements in the data set are affected, this modification has only a moderate impact on the estimated coefficients.

[13] The GED specification includes the normal distribution if ν is equal to 2. Values below 2 indicate heavy tail distributions. For most of the bond yield models in this study, the estimated ν lies between 1.25 and 1.5, whereas for the CDS data the respective estimator takes often values below 1. Except restrictive assumptions are made, $\nu > 1$ is required to guarantee the residuals' stationarity (cf. Rodriguez, 2010, 9). Therefore the parameter is restricted to the default value 1.5 when its estimator's value lies below 1.

DX_t is a vector for the controls entered as binary variables which means that they take the value one on days of important policy decisions, macro releases or rating downgrades, and zero otherwise.

3.3.4 Main Results

The model outputs for the reaction of sovereign CDS and bond yield spreads to communication by national representatives, EU officials and ECB Governing Council members are presented in Table 3.4. A summary of the results for both types of securities can be found in Table 3.3. Overall, the findings strongly support the notion that communication has an impact on financial markets. Across the majority of decision-makers considered in this study, the correlation between spread changes and the communication variables is in line with expectations, particularly when analysing CDS data. The largest effects are estimated for communication by German officials whereas the least coherent pattern emerges for statements by representatives of the PIIGS countries as well as the smaller eurozone members. Subsequently, I briefly review the main findings for each group of policy-makers.[14]

According to the estimated models, verbal interventions by the *German Chancellor and Minister of Finance* had the largest impact. As hypothesised in the earlier sections, dovish statements significantly lowered CDS and bond yield spreads, whereas hawkish statements pushed them upwards. These findings are highly consistent across the five countries, two securities, and four maturities considered. The coefficients associated with the two communication variables, $\hat{\beta}^{GER}_{DV}$ and $\hat{\beta}^{GER}_{HW}$, exhibit the expected sign in 32 of the 33 base models. Thereof, in 15 models both coefficients are significantly different from zero at the 90% confidence level. Given the range of coefficients, an average impact of communication by German officials on daily spread changes of about 1 to 2 percentage points seems plausible, whereby the estimated effects are somewhat larger in the CDS models.

In contrast to their German colleagues *French officials* rarely took a hawkish position in the public debate so that only the impact of their dovish comments are analysed. As one can immediately see, there is a considerable difference between the model outputs for CDS and bond yield spreads. 18 out of 19 estimations suggest that dovish statements are negatively correlated with changes in CDS spreads. Thereby, the respective coefficient is significantly different from zero in six out of 19 cases. However, these results do not hold when analysing bond yield spread changes, for which no systematic correlation with the respective communication variable can be observed. This apparent discrepancy between the results for CDS and bond yield spreads is discussed in more detail in section 3.3.6.

Similar to the French President and Finance Minister, leading *EU officials* predominantly

[14]For the sake of brevity, the results of the variance equation are not displayed in the following sections. Statements by representatives of Germany (hawkish and dovish), France (dovish), the smaller Eurozone members (hawkish) and the EU (dovish) are quite strongly associated with an increase in volatility, particularly in the CDS models. Regarding communication by officials from the PIIGS states (dovish), the smaller Eurozone members (dovish) as well as the ECB (all types) I find a less clear-cut pattern that tends to display negative coefficients.

Table 3.3: At a Glance: Results for the CDS- & GBY-Models, 01/01/2009 – 12/08/2011

CDS-Models		**Portugal**	**Ireland**	**Italy**	**Greece**	**Spain**	**Overall**	$\hat{\beta}$: Mean
Germany	Dovish	$-^{\star}$	$-^{\star}$	$-^{\star}$	$-^{\star}$	$-^{\star}$	$-^{\star}$	-0.0204
	Hawkish	$+^{\star}$	$+^{\star}$	$+^{\star}$	$+^{\star}$	$+^{\star}$	$+^{\star}$	0.0191
France	Dovish	$-^{\star}$	$-$	$-^{\star}$	$-$	$-^{\star}$	$-^{\star}$	-0.0130
PIIGS	Dovish	$+$	0	$+$	0	$-$	0	0.0013
Other	Dovish	$-$	$-$	$+^{\star}$	$+$	$-$	0	0.0009
Members	Hawkish	0	0	0	$-$	$-$	0	-0.0051
EU Officials	Dovish	$-^{\star}$	$-^{\star}$	$-$	$-$	$-^{\star}$	$-^{\star}$	-0.0093
ECB	Dovish	$-^{\star}$	$-$	$-$	$-$	0	$-$	-0.0078
(ECB specific)	Hawkish	$+^{\star}$	$+$	$+^{\star}$	$+$	$+^{\star}$	$+^{\star}$	0.0155
ECB	Dovish	$+$	$+$	$+$	0	$-$	0	0.0019
(political issues)	Hawkish	$+$	$+$	0	$+$	$+$	$+$	0.0044

$+^{\star}$ Consistently positive correlation, at least one estimate statistically significant (p<0.1); $+$ Consistently positive correlation, at least three estimates larger than zero; **0** Neither a consistently positive nor a consistently negative correlation; $-$ Consistently negative correlation, at least three estimates smaller than zero; $-^{\star}$ Consistently negative correlation, at least one estimate statistically significant (p<0.1).

GBY-Models		**Portugal**	**Ireland**	**Italy**	**Greece**	**Spain**	**Overall**	$\hat{\beta}$: Mean
Germany	Dovish	$-^{\star}$	$-^{\star}$	$-^{\star}$	$-^{\star}$	$-$	$-^{\star}$	-0.0093
	Hawkish	$+^{\star}$	$+^{\star}$	$+^{\star}$	$+$	$+^{\star}$	$+^{\star}$	0.0123
France	Dovish	0	0	$-$	0	0	0	-0.0017
PIIGS	Dovish	$-^{\star}$	0	$-$	0	0	0	-0.0039
Other	Dovish	0	0	0	0	$-$	0	-0.0010
Members	Hawkish	$-$	0	$-$	$-^{\star}$	0	$-$	-0.0034
EU Officials	Dovish	$-^{\star}$	$-$	$-^{\star}$	$-$	$-^{\star}$	$-^{\star}$	-0.0077
ECB	Dovish	$-^{\star}$	$-$	$-$	$-$	$+$	$-$	-0.0058
(ECB specific)	Hawkish	$+^{\star}$	0	$+^{\star}$	$+$	$+^{\star}$	$+^{\star}$	0.0096
ECB	Dovish	$+^{\star}$	$+^{\star}$	$+$	$+$	0	$+$	0.0048
(political issues)	Hawkish	0	$-^{\star}$	$-$	0	$+$	0	-0.0014

$+^{\star}$ Consistently positive correlation, at least one estimate statistically significant (p<0.1); $+$ Consistently positive correlation, at least three estimates larger than zero; **0** Neither a consistently positive nor a consistently negative correlation; $-$ Consistently negative correlation, at least three estimates smaller than zero; $-^{\star}$ Consistently negative correlation, at least one estimate statistically significant (p<0.1).

signaled high commitment to shield the peripheral eurozone countries. In all 33 models, the coefficient associated with their dovish statements is negative being statistically significant in twelve cases. Overall, the magnitude of the estimated coefficients suggests an average impact on spread changes between 0.75 an 1.25 percentage points.

Another fairly clear pattern emerges from the results on *ECB specific communication* (categories G–H). Hawkish statements on these matters are associated with a widening of CDS and bond yield spreads, whereby one finds statistically significant effects for Portuguese, Italian and Spanish securities. The correlation is less strong for the dovish analogue. Except for Spanish securities, the respective dummy produces consistently negative coefficients that are significantly different from zero in two out of 33 models and mainly indicate an impact between -0.5 and -1.5 percentage points.

The results for *ECB statements on politically dominated matters* (categories A–E) stand in sharp contrast to these findings. A glance at Table 3.3 reveals that the estimated impact is not only fairly inconsistent across the various countries considered but that in the bond yield models, they also tend to contradict the general intuition outlined above.

Table 3.4: Market Reaction to Hawkish (HW) and Dovish (DV) Comments by Politicial Leaders, EU and ECB Officials, Mean Equation (Sample: 01/01/09 – 12/08/11)

	Portugal				Ireland				Italy[b]			Greece				Spain			
	1 y	5 y	10 y	30^a y	1 y	5 y	10 y	30 y	5 y	10 y	30 y	1 y	5 y	10 y	30 y	1 y	5 y	10 y	30 y
***CDS Spreads**, Full Sample: January 1, 2009 - August 12, 2011 (N=682)*																			
GER, DV	−0.0095	−0.0185*	−0.0204*	−0.0226*	−0.0172*	−0.0178*	−0.0159*	−0.0198*	−0.0201*	−0.0230*	−0.0408*	−0.0153*	−0.0162*	−0.0081	−0.0088	−0.0237	−0.0286*	−0.0287*	−0.0341*
	(0.0096)	(0.0089)	(0.0104)	(0.0111)	(0.0052)	(0.0049)	(0.0075)	(0.0081)	(0.0097)	(0.0103)	(0.0144)	(0.0078)	(0.0071)	(0.0076)	(0.0073)	(0.0166)	(0.0117)	(0.0122)	(0.0124)
GER, HW	0.0247*	0.0177*	0.0189*	0.0188*	0.0120*	0.0113*	0.0117	0.0150*	0.0153	0.0162*	0.0230*	0.0198*	0.0138*	0.0167*	0.0183	0.0372*	0.0228*	0.0219*	0.0275*
	(0.0088)	(0.0091)	(0.0095)	(0.0103)	(0.0058)	(0.0061)	(0.0073)	(0.0076)	(0.0096)	(0.0095)	(0.0112)	(0.0071)	(0.0065)	(0.0090)	(0.0073)	(0.0169)	(0.0096)	(0.0100)	(0.0096)
FRA, DV	−0.0213*	−0.0137*	−0.0122	−0.0133	−0.0051	−0.0091	−0.0087	−0.0098	−0.0272*	−0.0236*	−0.0311*	0.0013	−0.0066	−0.0090	−0.0086	−0.0179	−0.0178*	−0.0112	−0.0148
	(0.0077)	(0.0080)	(0.0094)	(0.0074)	(0.0067)	(0.0064)	(0.0081)	(0.0084)	(0.0114)	(0.0115)	(0.0123)	(0.0105)	(0.0086)	(0.0094)	(0.0081)	(0.0179)	(0.0108)	(0.0107)	(0.0107)
PIIGS, DV	0.0079	0.0101	0.0117	0.0128	−0.0030	−0.0026	0.0059	0.0045	0.0043	0.0038	0.0038	0.0003	−0.0000	−0.0053	−0.0084	−0.0036	−0.0065	−0.0079	−0.0040
	(0.0079)	(0.0060)	(0.0109)	(0.0117)	(0.0064)	(0.0057)	(0.0086)	(0.0084)	(0.0093)	(0.0096)	(0.0120)	(0.0112)	(0.0087)	(0.0059)	(0.0064)	(0.0163)	(0.0101)	(0.0108)	(0.0102)
Other Members, DV	−0.0048	−0.0073	−0.0085	−0.0092	0.0039	−0.0063	−0.0013	−0.0049	0.0139	0.0251*	0.0258	0.0072	0.0084	0.0094	−0.0017	−0.0179	−0.0063	−0.0024	−0.0060
	(0.0091)	(0.0087)	(0.0099)	(0.0102)	(0.0075)	(0.0069)	(0.0091)	(0.0096)	(0.0133)	(0.0138)	(0.0204)	(0.0119)	(0.0089)	(0.0098)	(0.0107)	(0.0181)	(0.0108)	(0.0108)	(0.0108)
Other Members, HW	0.0022	−0.0063	−0.0036	0.0013	−0.0087	−0.0032	0.0011	0.0045	−0.0153	−0.0195	0.0055	−0.0092	−0.0106	−0.0110	−0.0130	−0.0224	−0.0092	−0.0091	−0.0077
	(0.0121)	(0.0115)	(0.0135)	(0.0139)	(0.0058)	(0.0060)	(0.0086)	(0.0084)	(0.0134)	(0.0140)	(0.0186)	(0.0091)	(0.0078)	(0.0083)	(0.0080)	(0.0178)	(0.0115)	(0.0118)	(0.0111)
EU Officials, DV	−0.0102	−0.0076	−0.0140*	−0.0146*	−0.0071	−0.0046	−0.0083	−0.0092*	−0.0078	−0.0086	−0.0087	−0.0061	−0.0069	−0.0054	−0.0016	−0.0177*	−0.0124*	−0.0145*	−0.0112
	(0.0066)	(0.0060)	(0.0072)	(0.0074)	(0.0051)	(0.0045)	(0.0051)	(0.0054)	(0.0077)	(0.0079)	(0.0086)	(0.0058)	(0.0050)	(0.0065)	(0.0065)	(0.0107)	(0.0071)	(0.0074)	(0.0069)
ECB (F-G), DV	−0.0138	−0.0166*	−0.0123	−0.0126	−0.0084	−0.0071	−0.0091	−0.0074	−0.0148	−0.0142	−0.0131	−0.0061	−0.0089	−0.0069	−0.0064	−0.0025	0.0000	0.0039	0.0077
	(0.0110)	(0.0097)	(0.0110)	(0.0119)	(0.0084)	(0.0086)	(0.0107)	(0.0115)	(0.0133)	(0.0151)	(0.0190)	(0.0064)	(0.0089)	(0.0053)	(0.0051)	(0.0189)	(0.0139)	(0.0136)	(0.0126)
ECB (F-G), HW	0.0095	0.0141*	0.0122	0.0068	0.0040	0.0048	0.0076	0.0013	0.0325*	0.0360*	0.0249*	0.0074	0.0094	0.0143	0.0135	0.0290*	0.0257*	0.0231*	0.0178
	(0.0122)	(0.0083)	(0.0087)	(0.0093)	(0.0063)	(0.0050)	(0.0060)	(0.0065)	(0.0109)	(0.0116)	(0.0121)	(0.0110)	(0.0084)	(0.0102)	(0.0095)	(0.0168)	(0.0106)	(0.0114)	(0.0113)
ECB (A-E), DV	0.0022	0.0043	0.0032	0.0041	0.0053	0.0050	0.0034	0.0035	0.0040	0.0033	0.0023	−0.0001	−0.0015	0.0016	0.0037	−0.0025	−0.0001	−0.0020	−0.0017
	(0.0067)	(0.0054)	(0.0062)	(0.0066)	(0.0044)	(0.0039)	(0.0052)	(0.0054)	(0.0073)	(0.0078)	(0.0079)	(0.0051)	(0.0043)	(0.0042)	(0.0043)	(0.0099)	(0.0063)	(0.0065)	(0.0062)
ECB (A-E), HW	0.0079	0.0061	0.0107	0.0104	−0.0008	0.0007	0.0017	0.0036	−0.0137	−0.0103	0.0045	0.0041	0.0055	0.0040	0.0022	0.0168	0.0099	0.0116	0.0086
	(0.0085)	(0.0079)	(0.0095)	(0.0102)	(0.0071)	(0.0071)	(0.0083)	(0.0079)	(0.0111)	(0.0116)	(0.0145)	(0.0051)	(0.0087)	(0.0057)	(0.0058)	(0.0226)	(0.0129)	(0.0132)	(0.0132)
***GBY Spreads**, Full Sample: January 1, 2009 - August 12, 2011 (N=682)*																			
GER, DV		−0.0104*	−0.0045	−0.0040		−0.0129*	−0.0070		−0.0066	−0.0049	−0.0162*		−0.0134*	−0.0137*	−0.0100*		0.0006	−0.0103	−0.0157*
		(0.0057)	(0.0058)	(0.0061)		(0.0073)	(0.0055)		(0.0100)	(0.0076)	(0.0065)		(0.0045)	(0.0045)	(0.0039)		(0.0084)	(0.0082)	(0.0063)
GER, HW		0.0092	0.0161*	0.0104*		0.0056	0.0189*		0.0255*	0.0148*	0.0150*		0.0050	0.0044	0.0018		0.0164*	0.0172*	0.0122*
		(0.0067)	(0.0060)	(0.0053)		(0.0080)	(0.0060)		(0.0125)	(0.0076)	(0.0059)		(0.0040)	(0.0038)	(0.0031)		(0.0084)	(0.0069)	(0.0047)
FRA, DV		0.0060	0.0021	−0.0016		0.0026	−0.0062		−0.0097	−0.0011	−0.0012		−0.0043	0.0042	−0.0027		0.0042	−0.0095	−0.0061
		(0.0072)	(0.0066)	(0.0055)		(0.0097)	(0.0061)		(0.0117)	(0.0078)	(0.0055)		(0.0050)	(0.0042)	(0.0044)		(0.0092)	(0.0075)	(0.0060)
PIIGS, DV		−0.0163*	−0.0004	−0.0094*		−0.0118	0.0013		−0.0164	0.0044	0.0015		−0.0021	−0.0011	−0.0006		−0.0060	0.0014	0.0005
		(0.0074)	(0.0076)	(0.0052)		(0.0096)	(0.0070)		(0.0116)	(0.0083)	(0.0058)		(0.0052)	(0.0051)	(0.0040)		(0.0101)	(0.0086)	(0.0061)
Other Members, DV		0.0087	−0.0138*	0.0053		0.0121	−0.0060		−0.0073	0.0112	0.0037		−0.0007	−0.0019	0.0015		−0.0022	−0.0038	−0.0034
		(0.0080)	(0.0067)	(0.0064)		(0.0105)	(0.0051)		(0.0108)	(0.0098)	(0.0073)		(0.0050)	(0.0045)	(0.0045)		(0.0095)	(0.0087)	(0.0058)
Other Members, HW		−0.0102	−0.0073	−0.0077		−0.0042	0.0001		−0.0016	−0.0049	−0.0043		−0.0024	−0.0062*	−0.0057		−0.0032	0.0053	0.0051
		(0.0075)	(0.0057)	(0.0063)		(0.0088)	(0.0072)		(0.0123)	(0.0093)	(0.0070)		(0.0040)	(0.0036)	(0.0039)		(0.0093)	(0.0102)	(0.0083)
EU Officials, DV		−0.0049	−0.0111*	−0.0014		−0.0079	−0.0062		−0.0144*	−0.0132*	−0.0089*		−0.0038	−0.0004	−0.0019		−0.0103	−0.0130*	−0.0094*
		(0.0049)	(0.0045)	(0.0042)		(0.0063)	(0.0038)		(0.0072)	(0.0053)	(0.0043)		(0.0031)	(0.0030)	(0.0029)		(0.0065)	(0.0054)	(0.0038)
ECB (F-G), DV		−0.0243*	−0.0092	−0.0088		−0.0181	−0.0107		−0.0106	−0.0036	−0.0007		−0.0014	−0.0049	−0.0045		0.0029	0.0065	0.0056
		(0.0087)	(0.0068)	(0.0068)		(0.0116)	(0.0071)		(0.0123)	(0.0094)	(0.0080)		(0.0040)	(0.0040)	(0.0039)		(0.0115)	(0.0100)	(0.0082)
ECB (F-G), HW		0.0091	0.0142*	0.0051		−0.0024	0.0041		0.0205*	0.0100	0.0084		0.0051	0.0020	0.0023		0.0263*	0.0184*	0.0106*
		(0.0071)	(0.0077)	(0.0054)		(0.0084)	(0.0081)		(0.0124)	(0.0075)	(0.0053)		(0.0048)	(0.0044)	(0.0039)		(0.0090)	(0.0085)	(0.0063)
ECB (A-E), DV		0.0083*	0.0072*	0.0036		0.0174*	0.0108*		0.0078	0.0043	0.0025		0.0001	0.0009	0.0056		−0.0040	0.0009	0.0023
		(0.0044)	(0.0040)	(0.0035)		(0.0055)	(0.0034)		(0.0075)	(0.0051)	(0.0037)		(0.0027)	(0.0026)	(0.0021)		(0.0088)	(0.0044)	(0.0033)
ECB (A-E), HW		−0.0145*	0.0015	0.0060		−0.0191*	−0.0106*		−0.0105	−0.0035	−0.0040		0.0061	0.0043	−0.0008		0.0044	0.0029	0.0047
		(0.0071)	(0.0054)	(0.0062)		(0.0099)	(0.0055)		(0.0084)	(0.0081)	(0.0080)		(0.0044)	(0.0045)	(0.0043)		(0.0088)	(0.0080)	(0.0059)

Notes: The table reports the daily reaction of sovereign CDS and bond yield (GBY) spreads to the communication variables. Standard errors are shown in brackets below the coefficients. * indicates significance at the 90% level or greater.
a The Portuguese sample for government bonds with 30 years maturity starts on May 27, 2009. **b** Italian CDS spreads for 1 year maturity contracts are excluded due to a gap in the sample.

Finally, the correlation between market movements and the communication of *national representatives of the PIIGS states* as well as the *smaller EMU member states* is rather inconsistent. In the case of hawkish statements by representatives of smaller EU members, the estimates' sign even tend to be counterintuitive. Considering that across both groups of agents the models imply a statistically significant correlation in only four out of 99 cases, the validity of the analysis seems not endangered due to these somewhat contradictory findings.

3.3.5 Robustness Analysis

In order to assess the robustness of the results presented above, the statistical model is in a first step re-estimated for two subsamples.[15] One subsample starts on *November 5, 2009* and ends on August 12, 2011. During the ten months excluded in this first robustness check, the level of communication was particularly low. At the same time, it is evident that the overall trend in CDS and bond yield spreads changed in autumn 2009 after Greece adjusted its estimated budget deficit upwards. Analysing data for this subperiod hardly affects the estimated coefficients compared to the full sample model; therefore these results are not discussed any further.[16]

The second subsample starts on January 1, 2009 and ends on *May 13, 2011.* By excluding the last two months from the original time series, one can rule out that the estimated effects are mostly driven by massive fluctuations in spreads during June and July 2011 or the somewhat ambiguous classification of statements on the voluntary involvement of private creditors in the Greek bailout (see Footnote 9). The model outputs for this second subsample are included in the appendix (see Table A.4). The variation in coefficients associated with hawkish comments on ECB specific issues is the most critical change observable when this subsample is used. In particular, the estimation output for Irish CDS and bond yield spreads indicate that the corresponding results in the main model are substantially driven by events during the last two months. Whereas in the full sample the correlation between hawkish ECB specific comments and Irish spreads is almost consistently positive, four out of six coefficients switch from a positive to a negative sign in the shortened sample. Furthermore, the size of the estimated effect drops in the Italian bond yield models, so that the respective coefficients are no longer statistically significant. However, the other series are affected to a much smaller extent: Although the estimated effect size for hawkish comments on ECB specific issues decreases across many models, the restricted sample still yields significant results for spreads of Portuguese (CDS & GBY), Italian (CDS) and Spanish (CDS & GBY) securities. Besides, in all models for Greek spreads, the estimates display the expected positive sign.

[15]Beside the robustness tests discussed in this section, I also compared the EGARCH models to the results obtained from OLS and GARCH(1,1) estimations. For the sake of brevity, these outputs are not provided here, but are available upon request. Compared to the OLS and GARCH models, the EGARCH estimation tends to produce slightly more conservative results. The most notable differences concern dovish statements by France and the ECB, which are more strongly associated with a decline in spreads when estimating GARCH and OLS models respectively. Overall, the conclusion is not changed though: The results across all three models seem to suggest, that statements by representatives of Germany, France, the ECB and the EU had an immediate impact on both types of securities, whereby hawkish statements display a clearer pattern than their dovish counterparts, especially in the bond yield context.

[16]The corresponding model outputs are available upon request.

Overall, there is little evidence suggesting that varying the sample period has a strong impact on the insights gained in the main model. Although dropping the very volatile period between May and August 2011 alters the estimation results moderately, the qualitative interpretation is not critically affected. One can still find clear patterns for statements by policy-makers of Germany, France and the EU administration as well as for ECB specific communication, whereas the results for statements by representatives of the PIIGS and the smaller eurozone members remain rather inconsistent and often counterintuitive.

As briefly mentioned in Foonote 6, one important issue could be that the benchmark securities, namely German CDS premia and bond yields, are also affected by communication. If this is the case, the results obtained so far have to be interpreted with caution. The model outputs for the corresponding robustness check are included in the appendix (see Table A.5). Estimating the effect of communication on sovereign bond yields without calculating the spread vis-à-vis the German Bund reveals a substantial decrease in the impact magnitude of communication compared to the findings in the main model. Most notably, the correlation between peripheral bond yields and dovish statements by German representatives is no longer consistently negative, except in the models for Greece (significant) and Ireland (insignificant). These results indicate that communication may affect German bond prices inversely to bond prices of the PIIGS countries. Indeed, regressing the benchmark bond yields on the communication variables gives significantly positive estimates for dovish statements by German representatives, positive estimates for dovish communication by French as well as EU officials, and negative estimates for hawkish comments by German and ECB representatives. On the one hand, this suggests that markets attach a higher risk to German sovereign debt when support for troubled countries is signalled. On the other hand, this implies that the effect size of the respective estimates may be upward 'biased' in the previous models. Interestingly, the inverse correlation between communication and German securities outlined above does not emerge in the CDS models, which is why using CDS premia instead of spreads vis-à-vis Germany does not substantially alter the main results presented so far. The following section discusses the apparent discrepancy between the reaction of CDS premia and bond yields as well as other issues.

3.3.6 Discussion of Results

The analysis presented in this paper suggests that statements by leading eurozone officials have the potential to move CDS and bond yield spreads. Although strongly depending on the source and content of statements as well as the type of security considered, the multivariate analysis suggests that in some cases the immediate average impact of public comments on relative spread changes may have amounted to more than 3 percentage points. Considering that in the same models the estimated effect of rating downgrades on daily spread changes varies between 1.5 and 2.5 percentage points, the impact of communication has to be acknowledged as fairly substantial.[17]

[17] It is important to emphasise, that this is a mere comparison of the very short run effects. As shown in a recent paper by Afonso, Furceri and Gomes (2012), rating downgrades affect sovereign CDS and bond yield spreads not

Having said that, two a priori unexpected findings need two be discussed further. First, the statistical models indicate a *discrepancy in the reaction of CDS and bond yield spreads*. Comparing the estimation outputs across the two types of securities reveals that ECB specific comments as well as communication by EU, French and German representatives tend to have a stronger impact on CDS spreads. Although this does not hold for each communication variable, country and maturity in the same manner, it is noteworthy that the outlined pattern can be well observed across all subsamples considered. The gap is particularly striking regarding the effects of dovish comments by representatives of France: whereas in the CDS models, dovish statements by French officials are strongly associated with declining spreads, no consistent correlation can be found in the models for bond yield spreads. Furthermore, robustness checks using CDS premia and bond yields instead of spreads versus Germany as dependent variables also emphasise the conclusion that the PIIGS' CDS premia reacted stronger to communication than the respective bond yields. A possible explanation for the apparent discrepancy between the two securities is put forward by Andenmatten and Brill (2011) who study the sovereign CDS and bond yield markets of peripheral eurozone countries after the collapse of Lehman Brothers. As their analysis suggests, fluctuations in CDS spreads mostly lead movements in bond yields, a finding they mainly explain with the higher liquidity in the CDS market of countries in financial trouble.[18] Results by Afonso, Furceri and Gomes (2012, 614), who analyse the impact of sovereign credit ratings on European CDS and bond yield spreads, also support this reasoning. They find that bond yields react more sluggish and less strong to changes in the credit rating than CDS spreads. Since the statistical framework of the study at hand assumes that financial markets react immediately to communication, i.e. on the same trading day, the reaction lag of bond yields could explain the observed differences between the two securities analysed.

Second, the statistical results reveal a *more robust pattern between hawkish statements and financial market movements* than between dovish statements and spread changes. This becomes especially apparent regarding the findings for ECB specific communication as well as the results for German statements on bond yields in the robustness section.[19] Empirical studies on the impact of sovereign credit ratings report similiar findings suggesting that responses to positive and negative information are asymmetric. For instance, Afonso, Furceri and Gomes (2012, 612) find a strong reaction of both CDS and bond yield spreads to rating downgrades whereas the reaction to rating upgrades is much more muted, especially in the bond yield models where they cannot find significant correlations. Referring to the literature on decision making under risk (eg. Kahneman and Tversky, 1979; Bowman, Minehart and Rabin, 1999), the explanation put forward by Afonso, Furceri and Gomes (2012, 612) is that positive news have a weaker impact on

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only in the first days after the announcement but rather have a long-term impact lasting several months.

[18]In this respect Andenmatten and Brill (2011, 299) write: "For countries considered safe, the government bond market is in general more liquid than the sovereign CDS market [...] However, for countries in financial trouble the bond market becomes more illiquid than the sovereign CDS market." This observation may also explain why dovish statements by German representatives, which basically signal higher financial outlays/risks for the core countries, are stronger correlated with German bond yields rather than German CDS premia.

[19]Although the findings outline a more consistent pattern for hawkish than for dovish communication, the statistical analysis does not strictly support different impact magnitudes between the two types of statements: Wald-tests suggest that the absolute values of the estimated coefficients for hawkish and dovish of comments by ECB policy-makers as well as German politicians are not significantly different from each other.

individuals than negative news, since agents care more strongly about utility losses than about gains of equal magnitudes.

What might additionally attenuate the estimated impact of dovish statements compared to hawkish comments is the study's use of dummy variables that do not control for market expectations about the content of communication.[20] Regarding highly repetitive statements, for example, its seems reasonable to assume that they have a rather low individual information value and are therefore less likely to impact financial markets than non-repetitive comments. This consideration may be relevant, since the number of dovish statements in the sample is more than twice as large as the number of hawkish comments. Furthermore, it is noteworthy that the ECB's dovish communication about sovereign bond buys and the collateral framework mainly fell into the period following May 2010, and hence was largely limited to reassure markets about the duration of the ECB's rescue measures rather than providing signals on potential future interventions. Both aspects may indicate that dovish statements had on average a lower information value than hawkish comments, which could – at least partially – drive the asymmetric reaction of spreads to dovish and hawkish communication in the paper's statistical analysis.

3.4 Conclusion

In a television broadcast on the debt crisis, an exchange dealer known as "Mr. Dax", was asked whether financial markets react to communication by German politicians. To that he replied: "Definitely not [...]. I think politicians overestimate themselves, if they assume that their words have the power to unsettle traders working at an investment bank like Goldman Sachs."[21]

The present paper's objective is to answer a similar question. It examines the effects of communication by ECB governing council members, EU officials, as well as national representatives on the PIIGS' CDS and bond yield spreads during the first phase of the European sovereign debt crisis. The focus lies on *dovish statements* that signal strong determination in the rescue of indebted countries, and *hawkish statements* indicating limited commitment to support the PIIGS and protect its creditors.

The results based on a multivariate analysis in the EGARCH framework using daily data for the period from January 1, 2009 to August 12, 2011 reject the proposition by "Mr. Dax" quoted above. My findings suggest that hawkish comments caused an increase in spreads, whereas statements signaling high commitment to shield peripheral eurozone countries held the opposite effect. Dovish comments display a somewhat weaker pattern regarding sign and significance than

[20]Controlling for the individual information value of statements would clearly be a considerable refinement, however, I do not do so for two reasons: First, identifying market expectations about the content of communication is practically impossible. Second, the estimates are well behaved in the sense that not controlling for market expectations most likely holds too conservative estimates rather than an overestimation.

[21]Original statement: "Das war sicherlich nicht so [...]. Ich glaube die Politik hat ein bisschen Selbstüberschätzung anzunehmen, dass eine Investmentbank wie Goldman Sachs in New York, dass dort die Handelsabteilung in Unruhe gerät wenn in Deutschland jemand etwas sagt." Dirk Müller as guest in the political talkshow *Günther Jauch. Die schwarz-gelbe Pleite! Kann diese Regierung noch den Euro retten?* broadcasted by *Das Erste*, September 13, 2011.

hawkish comments, especially in the bond yields models, which might indicate an asymmetric response of the sovereign bond market to good and bad news, respectively. With respect to the source of communication, the clearest pattern is found for representatives of Germany, but for French politicians and leading EU officials the models reveal fairly consistent correlations too. Regarding communication by ECB officials, the statistical analysis shows that alongside the source of a message, its content played an important role as well. Whereas no coherent effects on CDS and bond yield spreads are found for ECB statements on matters within the political domain, there is some evidence that communication on government bond purchases and the collateral framework moved financial markets. No consistent pattern can be found for communication by politicians of the smaller eurozone member countries and the PIIGS states indicating that they received the least attention by financial markets.

A. Appendix

Table A.1: Examples of Statements by EMU Policymakers and their Classification

Dovish Signal: High Commitment	**Hawkish Signal: Limited Commitment**
A) Financial Aid to PIIGS	
Statements signaling the policy-maker's support for a bailout of troubled eurozone countries as well as comments confirming that a specific member will receive financial support from the EFSF. In the pre-EFSF period, comments suggesting that the eurozone is ready to step in for its member, such as "we will show solidarity with indebted countries" or "we have options to respond", are also included in this category.	Statements rejecting coordinated financial aid within the eurozone or comments emphasizing the self-responsibility of Euro members, such as "they have to solve their own problems". In the run-up to bailout decisions, i.e. April 2010 or spring 2011, comments signaling reluctance to approve aid measures, such as "the decision could still be negative" or "the measures cannot be approved without strict conditions", are also included in this category.
Example: *"The rules say that within the eurozone countries should not help each other. However, if it came to a serious situation, all the eurozone countries would have to help." (P. Steinbrück, 16/02/09, Reuters)*	***Example:*** *"The eurozone is a monetary zone which holds us together, [...] there's a no bailout system and we have to deliver on commitments we have made." (C. Lagarde, 29/01/10, Dow Jones)*
B) Size of EFSF	
Statements calling for an increase in the EFSF's lending power as well as comments signaling the policy-maker's willingness to support additional funding.	Staments voicing opposition to a raise in the EFSF's budget as well as comments emphasizing that the budget is adequate and a boost not necessary.
Example: *"[T]he financing capacity must be reinforced and the scope of activities of the EFSF should be widened." (J. Barroso, 12/01/11, AFP)*	***Example:*** *"In our view it is not necessary at the present time to increase the capacity of the EFSF." (W. Schäuble, 14/02/2011, Reuters)*
C) Expulsion/Exit of EMU members	
Statements suggesting that neither an exit nor an expulsion of eurozone members is possible/realistic or should be so in the future.	Statements suggesting that an exit or an expulsion of eurozone members is possible/realistic or should be so in the future.
Example: *"This idea [member state expulsion] would require a treaty change and I have some reservations whether it is in line with the principles of the founding fathers of an ever-closer union." (O. Rehn, 14/04/10, Reuters)*	***Example:*** *"We need stricter rules – that means, in an extreme emergency, having the possibility of removing from the euro area a country that does not get its finances in order." (W. Schäuble, 15/03/10, AFP)*
D) Sovereign Default / Orderly Sovereign Insolvency Procedure / Private Sector Involvement	
Statements categorically ruling out sovereign defaults or enforced private sector involvements in the rescue of eurozone members. The policy-maker denies/opposes such scenarios both in the short- and long-term.	Statements confirming the possiblity of a sovereign default as well as calls for orderly insolvency procedures or private sector involvements. Also includes comments that deny a private sector role in current bailouts but signal the speaker's demand/support for a respective mechanism in future interventions.
Example: *"In this context [bank stress tests], it was a deliberate choice that we will not assume a default of any EU member state and of course that's linked to our policy". (O. Rehn, 20/06/11, Reuters)*	***Example:*** *"Have politicians got the courage to make those who earn money share the risk as well?[...] This is about the primacy of politics, this is about the limits of the markets." (A. Merkel, 24/11/10, Reuters)*
E) Voluntary Private Sector Involvement / Vienna Initiative	
Statements opposing any volutary private sector involvement or comments placing a strong emphasis on the dangers associated with such measures.	Statements supporting voluntary private sector contributions are also classified as dovish communication. See footnote 9 for an explanation.
Example: *"If creditors were offered terms to voluntarily lengthen the maturity of the debt they held, the implications would be that they would lose more if they refused [...]. Then it is not voluntary but a forced restructuring. [...] So 'soft restructurings' do not exist." (L. Bini Smaghi, 30/05/11, MNI)*	***Example:*** *"[W]e must also convince all our partners in the financial sector to participate. It's a voluntary participation to maintain their commitments in terms of credit." (D. Reynders, 14/06/11, Dow Jones)*
F) Changes in ECB's Collateral Framework (ECB only)	
Statements indicating a loosening of the ECB's collateral rules such that specific sovereign bonds would still meet the requirements after a potential downgrade. Comments denying plans for a tightening of the colleteral rules.	Statements that rule out a loosening or indicate a tightening of the ECB's collateral rules. Comments signaling that the ECB would no longer accept specific sovereign bonds as collateral after a further decline in their rating.
Example: *"My working assumption is that we won't have difficulties [with the CF], because there won't be downgrading [...]. If it should appear that this working assumption is too optimistic, then we would look at the situation." (J. Trichet, 22/03/10, MNI.)*	***Example:*** *"The ECB will not change plans to tighten its collateral rules [...]. The ECB will continue to apply its collateral framework the same way to all countries." (L. Papademos, 18/12/09, Reuters)*
G) Government Bond Purchases / Security Market Program (ECB only)	
Statements indicating that sovereign bond purchases are considered as a policy option. Following the launch of the SMP, comments suggesting that the SMP is fully operating or statements denying that the SMP will stop in the near future are also included in this category.	Statements that rule out any form of sovereign bond buying programs by the ECB. Following the launch of the SMP, comments voicing opposition to the SMP are also included in this category.
Example: *"I have never said that the securities market program had been interrupted. [...] It is an ongoing programme." (J. Trichet, 04/08/11, AFP & Reuters)*	***Example:*** *Asked whether it would be an issue for the ECB to buy Greek government bonds, Jürgen Stark said it isn't being discussed at the present. (28/04/10, Dow Jones)*

Factiva Search

The Factiva data base was scanned using terms of the following form:<The Decision-Maker's Last Name>and<A Crisis Related Key Word>, eg. merkel and default. The scan was restricted to the headline and first paragraph, so that only newswire reports focusing on the relevant information were selected. Five major news agencies were considered, namely Reuters, Dow Jones Newswires, Agence France-Press, Associated Press Newswires, and Market News International.

Key Words: *bailout, bail out, bond buy(-ing), bond purchase(-ing), cds, collateral, credit event, debt, default, efsf, eurozone crisis, government debt, greece, greek, haircut, insolvency, ireland, irish, italy, italian, portugal, portuguese, private creditor(s), private investor(s), private sector, public finances, reform, restructure(-ing), solidarity, sovereign debt.*

Table A.2: Average Changes in Spreads on Days with and without Communication

GBY: 5y, 10y, 30y.		**Portugal**		**Ireland**		**Italy**		**Greece**		**Spain**	
CDS: 1y, 5y, 10y, 30y.		CDS	GBY	CDS	GBY	CDS	GBY	CDS	GBY	CDS	GBY
Germany	Dovish	−0.018	−0.001	−0.016	−0.007	−0.016	0.002	−0.017	−0.012	−0.019	0.002
	No Com.	0.007	0.004	0.004	0.003	0.003	0.001	0.005	0.004	0.005	0.002
	Hawkish	0.038	0.024	0.022	0.021	0.025	0.028	0.020	0.015	0.039	0.030
France	Dovish	−0.001	0.002	−0.002	0.001	−0.014	−0.004	0.005	−0.004	−0.004	0.001
	No Com.	0.008	0.005	0.004	0.004	0.004	0.003	0.005	0.004	0.005	0.003
	Hawkish	–	–	–	–	–	–	–	–	–	–
POR, IRE, ITA, GRE, SPA	Dovish	0.004	−0.001	0.008	0.001	−0.007	−0.008	−0.007	−0.007	−0.002	−0.002
	No Com.	0.008	0.006	0.004	0.005	0.005	0.004	0.006	0.004	0.006	0.004
	Hawkish	–	–	–	–	–	–	–	–	–	–
Other Eurozone Members	Dovish	−0.003	0.009	−0.014	0.002	0.012	0.005	−0.001	−0.000	−0.006	0.003
	No Com.	0.007	0.005	0.004	0.004	0.003	0.002	0.005	0.003	0.006	0.003
	Hawkish	0.022	0.015	0.012	0.014	0.018	0.019	0.008	0.007	0.010	0.019
EU Officials	Dovish	−0.000	−0.004	−0.009	−0.000	−0.006	−0.006	−0.004	−0.005	−0.007	−0.004
	No Com.	0.008	0.007	0.006	0.005	0.005	0.004	0.006	0.004	0.007	0.005
	Hawkish	–	–	–	–	–	–	–	–	–	–
ECB (A-G)	Dovish	0.003	0.007	0.004	0.007	−0.002	0.006	0.002	0.005	0.000	0.003
	No Com.	0.008	0.005	0.004	0.004	0.005	0.002	0.005	0.002	0.006	0.003
	Hawkish	0.017	0.010	0.001	0.003	0.009	0.008	0.013	0.008	0.012	0.014

Notes: Mean changes in CDS and bond yield spreads are based on unweighted averages across the various maturities considered.

Table A.3: The Control Variables

Variable	**Source**	**Coding**	**Description**
Credit Rating Development	Moody's, Fitch, Standard & Poor's	-1 = Downgrade 0 = No Change 1 = Upgrade	A measure for changes in a country's sovereign credit rating. Both *credit rating announcements* and *revisions in the rating outlooks* from the three main credit agencies are taken into account.
Credit Rating Spillovers	Moody's, Fitch, Standard & Poor's	-1 = Downgrade 0 = No Change 1 = Upgrade	A measure for credit rating spillovers between the 5 peripheral eurozone countries. It accounts for any rating down- respectively upgrades among the PIIGS, excluding the country under conisderation.
Macro News Surprise	Bloomberg, Forexpros.com	$\frac{(release-forecast)}{std.dev.(release)}$	The surprise component of macro news is constructed by subtracting market expectations obtained through a survey of market participants from the actually released figure, and normalising this difference by the standard deviation of the actual releases. Set of macro news: GDP (PO, IR, IT, GR, SP), the unemployment rate (IT, GR, SP), industrial production (IT, SP), and retail sales (IT).
Domestic Policy & Events	Factsheets, Timelines, and reports by Reuters, AFP, and Dow Jones.	-1 = Tightening 0 = No Event 1 = Easing	Captures various political events and policy decision, which may have led to a (de-)stabilisation in the respective country. These include governmental crises, revisions of budget deficit forecasts, and announcements or parliamentary votes on economic reforms as well as austerity programs.
Policy Decisions on European level	Factsheets, Timelines, and reports by Reuters, AFP, and Dow Jones.	-1 = Unsupportive 0 = No Event 1 = Supportive	Comprises information on crisis related policy decisions on the European level. It includes for instance changes in the ECB's collateral framework, agreements on the EFSF or ESM, the disbursement of loans, and interest rate decision by the ECB.
Structural Change: 05/11/09		0=After 05/11/09 1=Until 05/11/09	A look at the Data (or Figure 3.1) reveals, that the trend of spreads between Jan. & Oct. 2009 was slightly negative. After Greece revised its budget deficit on 05/11/2009, one can observe a shift towards a positive trend. The inclusion of this dummy should account for the shift.
Autoregressive terms		$\sum_{i=1}^{max.4} \gamma_i s_{t-i}$	In order to control for autocorrelation in market movements, autoregressive terms up to order 4 are used in the models. In most cases, it is sufficient to include the one-period lag of spread changes.

Table A.4: Market Reaction to Hawkish (HW) and Dovish (DV) Comments by Politicial Leaders, EU and ECB Officials, Mean Equation (Sample: 01/01/09 –13/05/11)

	Portugal				Ireland				Italy[b]			Greece				Spain			
	1 y	5 y	10 y	30[a] y	1 y	5 y	10 y	30 y	5 y	10 y	30 y	1 y	5 y	10 y	30 y	1 y	5 y	10 y	30 y
***CDS Spreads**, Restricted Sample: January 1, 2009 - Mai 13, 2011 (N=616)*																			
GER, DV	−0.0262*	−0.0413*	−0.0480*	−0.0541*	−0.0237*	−0.0256*	−0.0302*	−0.0326*	−0.0308*	−0.0335*	−0.0572*	−0.0149	−0.0214*	−0.0189*	−0.0197*	−0.0318*	−0.0363*	−0.0430*	−0.0456*
	(0.0154)	(0.0146)	(0.0192)	(0.0228)	(0.0060)	(0.0054)	(0.0152)	(0.0115)	(0.0121)	(0.0123)	(0.0131)	(0.0115)	(0.0069)	(0.0115)	(0.0106)	(0.0171)	(0.0125)	(0.0167)	(0.0175)
GER, HW	0.0317*	0.0311*	0.0354*	0.0336*	0.0136*	0.0118*	0.0152*	0.0164*	0.0152	0.0154	0.0282*	0.0248*	0.0114*	0.0152	0.0132	0.0337*	0.0320*	0.0275*	0.0241*
	(0.0111)	(0.0087)	(0.0097)	(0.0113)	(0.0062)	(0.0061)	(0.0079)	(0.0085)	(0.0097)	(0.0098)	(0.0101)	(0.0105)	(0.0061)	(0.0108)	(0.0092)	(0.0204)	(0.0090)	(0.0105)	(0.0113)
FRA, DV	−0.0261*	−0.0253*	−0.0275*	−0.0261*	−0.0094	−0.0121*	−0.0098	−0.0148	−0.0196	−0.0197	−0.0247*	0.0038	−0.0117*	−0.0063	−0.0069	−0.0131	−0.0176	−0.0115	−0.0151
	(0.0101)	(0.0078)	(0.0097)	(0.0094)	(0.0071)	(0.0071)	(0.0085)	(0.0093)	(0.0133)	(0.0129)	(0.0131)	(0.0157)	(0.0069)	(0.0128)	(0.0103)	(0.0218)	(0.0114)	(0.0129)	(0.0131)
PIIGS, DV	0.0128	0.0152*	0.0134*	0.0178*	−0.0056	−0.0050	−0.0074	−0.0089	0.0115	0.0111	−0.0042	0.0008	−0.0027	−0.0057	−0.0096	−0.0032	−0.0034	−0.0038	−0.0040
	(0.0095)	(0.0084)	(0.0099)	(0.0106)	(0.0075)	(0.0068)	(0.0089)	(0.0097)	(0.0103)	(0.0106)	(0.0117)	(0.0112)	(0.0067)	(0.0075)	(0.0077)	(0.0186)	(0.0092)	(0.0111)	(0.0123)
Other Members, DV	−0.0074	−0.0084	−0.0158	−0.0128	−0.0171*	−0.0201*	−0.0169*	−0.0156*	0.0059	0.0218	0.0255	0.0097	−0.0013	0.0056	−0.0208	−0.0248	−0.0239	−0.0118	−0.0148
	(0.0129)	(0.0109)	(0.0142)	(0.0127)	(0.0078)	(0.0074)	(0.0089)	(0.0084)	(0.0179)	(0.0173)	(0.0162)	(0.0141)	(0.0067)	(0.0158)	(0.0191)	(0.0176)	(0.0210)	(0.0116)	(0.0127)
Other Members, HW	0.0108	0.0071	0.0017	0.0011	−0.0153*	−0.0094	−0.0121	−0.0084	−0.0156	−0.0181	−0.0141	−0.0143	−0.0126*	−0.0157	−0.0173	−0.0195	−0.0177	−0.0219	−0.0239
	(0.0263)	(0.0150)	(0.0170)	(0.0208)	(0.0066)	(0.0070)	(0.0092)	(0.0102)	(0.0187)	(0.0202)	(0.0167)	(0.0165)	(0.0068)	(0.0144)	(0.0119)	(0.0227)	(0.0177)	(0.0151)	(0.0184)
EU Officials, DV	−0.0082	−0.0057	−0.0108	−0.0093	−0.0053	−0.0032	−0.0038	−0.0064	−0.0092	−0.0084	−0.0193*	−0.0081	−0.0088*	−0.0050	−0.0021	−0.0128	−0.0097	−0.0091	−0.0082
	(0.0082)	(0.0072)	(0.0083)	(0.0090)	(0.0063)	(0.0059)	(0.0065)	(0.0068)	(0.0090)	(0.0090)	(0.0131)	(0.0083)	(0.0049)	(0.0079)	(0.0074)	(0.0111)	(0.0072)	(0.0079)	(0.0088)
ECB (F-G), DV	−0.0187	−0.0169*	−0.0166	−0.0225*	−0.0046	−0.0031	−0.0003	−0.0009	−0.0175	−0.0167	−0.0169	−0.0077	−0.0056	−0.0081	−0.0076	−0.0023	−0.0017	0.0016	0.0056
	(0.0142)	(0.0095)	(0.0107)	(0.0129)	(0.0106)	(0.0103)	(0.0118)	(0.0132)	(0.0147)	(0.0158)	(0.0151)	(0.0075)	(0.0083)	(0.0073)	(0.0064)	(0.0178)	(0.0132)	(0.0148)	(0.0161)
ECB (F-G), HW	0.0201	0.0270*	0.0365*	0.0289*	−0.0124	−0.0085	0.0042	−0.0040	0.0245*	0.0246*	0.0353*	0.0033	0.0056	0.0066	0.0040	0.0006	0.0204*	0.0172	0.0169
	(0.0178)	(0.0104)	(0.0114)	(0.0135)	(0.0088)	(0.0075)	(0.0085)	(0.0059)	(0.0145)	(0.0139)	(0.0179)	(0.0126)	(0.0086)	(0.0110)	(0.0088)	(0.0243)	(0.0114)	(0.0148)	(0.0158)
ECB (A-E), DV	0.0046	0.0053	0.0068	0.0099	0.0046	0.0043	0.0035	0.0059	0.0041	0.0036	0.0089	0.0020	−0.0010	−0.0018	0.0036	−0.0059	−0.0042	−0.0029	−0.0013
	(0.0076)	(0.0056)	(0.0061)	(0.0064)	(0.0046)	(0.0042)	(0.0054)	(0.0060)	(0.0079)	(0.0083)	(0.0081)	(0.0058)	(0.0038)	(0.0048)	(0.0045)	(0.0100)	(0.0057)	(0.0064)	(0.0074)
ECB (A-E), HW	−0.0005	−0.0032	0.0009	−0.0037	−0.0020	0.0015	−0.0035	−0.0011	−0.0212*	−0.0153	0.0066	−0.0002	0.0065	0.0040	0.0030	0.0105	0.0075	0.0019	−0.0019
	(0.0076)	(0.0056)	(0.0092)	(0.0109)	(0.0072)	(0.0072)	(0.0054)	(0.0095)	(0.0121)	(0.0123)	(0.0146)	(0.0104)	(0.0077)	(0.0077)	(0.0066)	(0.0270)	(0.0081)	(0.0147)	(0.0162)
***GBY Spreads**, Restricted Sample: January 1, 2009 - Mai 13, 2011 (N=616)*																			
GER, DV		−0.0110	−0.0108	−0.0093		−0.0149*	−0.0102		−0.0009	−0.0058	−0.0103*		−0.0167*	−0.0159*	−0.0149*		−0.0004	−0.0129	−0.0139*
		(0.0097)	(0.0081)	(0.0110)		(0.0090)	(0.0075)		(0.0101)	(0.0113)	(0.0055)		(0.0058)	(0.0075)	(0.0058)		(0.0098)	(0.0105)	(0.0076)
GER, HW		0.0070	0.0182*	0.0073		0.0083	0.0153*		0.0304*	0.0153*	0.0140*		0.0049	0.0021	0.0028		0.0184*	0.0221*	0.0129*
		(0.0090)	(0.0062)	(0.0062)		(0.0108)	(0.0072)		(0.0124)	(0.0080)	(0.0055)		(0.0046)	(0.0036)	(0.0034)		(0.0095)	(0.0093)	(0.0060)
FRA, DV		0.0092	0.0060	−0.0018		0.0029	−0.0031		−0.0165	0.0035	−0.0046		−0.0076	0.0067	−0.0012		0.0142	−0.0063	−0.0019
		(0.0101)	(0.0087)	(0.0066)		(0.0118)	(0.0069)		(0.0054)	(0.0050)	(0.0049)		(0.0054)	(0.0046)	(0.0052)		(0.0092)	(0.0109)	(0.0076)
PIIGS, DV		−0.0221	0.0056	−0.0034		−0.0161	−0.0014		−0.0248*	−0.0000	−0.0013		−0.0053	−0.0036	0.0003		−0.0035	0.0133	0.0031
		(0.0114)	(0.0089)	(0.0064)		(0.0125)	(0.0078)		(0.0114)	(0.0092)	(0.0067)		(0.0061)	(0.0047)	(0.0044)		(0.0105)	(0.0090)	(0.0073)
Other Members, DV		0.0080	−0.0211*	0.0020		0.0037	−0.0160*		−0.0165*	0.0079	−0.0010		−0.0060	−0.0070	−0.0014		−0.0186	−0.0052	−0.0056
		(0.0118)	(0.0083)	(0.0075)		(0.0126)	(0.0074)		(0.0126)	(0.0133)	(0.0085)		(0.0050)	(0.0047)	(0.0056)		(0.0126)	(0.0168)	(0.0080)
Other Members, HW		−0.0130	−0.0154*	0.0039		−0.0033	0.0014		−0.0123	0.0012	0.0006		−0.0030	−0.0069	−0.0096*		−0.0003	0.0129	0.0123
		(0.0124)	(0.0084)	(0.0095)		(0.0126)	(0.0132)		(0.0187)	(0.0123)	(0.0112)		(0.0051)	(0.0047)	(0.0052)		(0.0126)	(0.0106)	(0.0106)
EU Officials, DV		−0.0043	−0.0112*	−0.0026		−0.0026	−0.0031		−0.0158*	−0.0131*	−0.0156*		−0.0070*	−0.0017	−0.0026		−0.0080	−0.0090	−0.0086*
		(0.0072)	(0.0053)	(0.0054)		(0.0083)	(0.0050)		(0.0076)	(0.0060)	(0.0040)		(0.0038)	(0.0034)	(0.0032)		(0.0077)	(0.0062)	(0.0043)
ECB (F-G), DV		−0.0237*	−0.0097	−0.0070		−0.0011	−0.0098		−0.0154	−0.0054	−0.0040		0.0011	−0.0020	−0.0028		−0.0016	0.0002	0.0022
		(0.0131)	(0.0077)	(0.0070)		(0.0152)	(0.0086)		(0.0115)	(0.0098)	(0.0044)		(0.0042)	(0.0044)	(0.0044)		(0.0117)	(0.0089)	(0.0069)
ECB (F-G), HW		0.0014	0.0154	0.0145*		−0.0141	−0.0010		0.0038	0.0042	0.0020		0.0059	0.0028	0.0051		0.0308*	0.0160*	0.0089
		(0.0126)	(0.0098)	(0.0082)		(0.0129)	(0.0119)		(0.0169)	(0.0095)	(0.0080)		(0.0060)	(0.0054)	(0.0049)		(0.0124)	(0.0095)	(0.0081)
ECB (A-E), DV		0.0136*	0.0069	0.0040		0.0226*	0.0120*		0.0126	0.0055	0.0083		0.0022	0.0032	0.0032		−0.0075	0.0003	0.0035
		(0.0058)	(0.0045)	(0.0040)		(0.0103)	(0.0038)		(0.0082)	(0.0056)	(0.0080)		(0.0030)	(0.0028)	(0.0024)		(0.0060)	(0.0049)	(0.0039)
ECB (A-E), HW		−0.0084	−0.0065	0.0082		−0.0246*	−0.0137*		−0.0128	−0.0026	−0.0051		0.0068	0.0056	−0.0019		−0.0077	−0.0004	−0.0003
		(0.0092)	(0.0045)	(0.0068)		(0.0103)	(0.0063)		(0.0086)	(0.0082)	(0.0044)		(0.0049)	(0.0048)	(0.0046)		(0.0088)	(0.0122)	(0.0062)

Notes: The table reports the daily reaction of sovereign CDS and bond yield (GBY) spreads to the communication variables. Standard errors are shown in brackets below the coefficients. * indicates significance at the 90% level or greater.
a The Portuguese sample for government bonds with 30 years maturity starts on May 27, 2009. **b** Italian CDS spreads for 1 year maturity contracts are excluded due to a gap in the sample.

Table A.5: Market Reaction to Hawkish (HW) and Dovish (DV) Comments by Politicial Leaders, EU and ECB Officials, Mean Equation (01/01/09 – 12/08/11, NO SPREADS)

	Portugal				Ireland				Italy			Greece				Spain			
	1 y	5 y	10 y	30^a y	1 y	5 y	10 y	30 y	5 y	10 y	30 y	1 y	5 y	10 y	30 y	1 y	5 y	10 y	30 y
***CDS Premia**, Full Sample: January 1, 2009 - August 12, 2011 (N=682)*																			
GER, DV	−0.0146*	−0.0248*	−0.0219*	−0.0238*	−0.0159*	−0.0164*	−0.0157*	−0.0150*	−0.0206*	−0.0219*	−0.0236*	−0.0119	−0.0089	−0.0068	−0.0043	−0.0283*	−0.0246*	−0.0268*	−0.0254*
	(0.0085)	(0.0073)	(0.0079)	(0.0083)	(0.0052)	(0.0051)	(0.0071)	(0.0074)	(0.0084)	(0.0084)	(0.0090)	(0.0075)	(0.0075)	(0.0072)	(0.0074)	(0.0149)	(0.0099)	(0.0096)	(0.0094)
GER, HW	0.0209*	0.0223*	0.0192*	0.0177*	0.0127*	0.0125*	0.0151*	0.0158*	0.0153*	0.0146*	0.0144*	0.0195*	0.0125	0.0143	0.0099	0.0385*	0.0215*	0.0216*	0.0215*
	(0.0095)	(0.0079)	(0.0091)	(0.0094)	(0.0062)	(0.0061)	(0.0067)	(0.0069)	(0.0082)	(0.0078)	(0.0085)	(0.0072)	(0.0077)	(0.0087)	(0.0066)	(0.0163)	(0.0086)	(0.0077)	(0.0083)
FRA, DV	−0.0204*	−0.0178*	−0.0103	−0.0113	−0.0063	−0.0094	−0.0104	−0.0092	−0.0203*	−0.0205*	−0.0208*	0.0016	−0.0064	−0.0096	−0.0090	−0.0179	−0.0165*	−0.0104	−0.0140
	(0.0107)	(0.0064)	(0.0087)	(0.0089)	(0.0064)	(0.0058)	(0.0074)	(0.0073)	(0.0100)	(0.0095)	(0.0100)	(0.0106)	(0.0093)	(0.0088)	(0.0074)	(0.0170)	(0.0095)	(0.0084)	(0.0092)
PIIGS, DV	0.0051	0.0085	0.0097	0.0094	−0.0033	−0.0034	0.0039	0.0063	0.0030	−0.0042	0.0053	0.0015	−0.0002	−0.0037	−0.0078	−0.0023	−0.0036	−0.0033	−0.0012
	(0.0113)	(0.0066)	(0.0098)	(0.0104)	(0.0060)	(0.0051)	(0.0073)	(0.0075)	(0.0077)	(0.0075)	(0.0080)	(0.0106)	(0.0081)	(0.0057)	(0.0057)	(0.0148)	(0.0089)	(0.0084)	(0.0088)
Other Members, DV	−0.0058	−0.0029	−0.0100	−0.0093	−0.0028	−0.0053	−0.0047	−0.0044	0.0074	0.0124	0.0145	0.0030	0.0046	0.0062	−0.0081	−0.0161	−0.0093	−0.0066	−0.0084
	(0.0101)	(0.0078)	(0.0086)	(0.0089)	(0.0072)	(0.0065)	(0.0083)	(0.0085)	(0.0118)	(0.0109)	(0.0113)	(0.0115)	(0.0089)	(0.0092)	(0.0099)	(0.0172)	(0.0098)	(0.0090)	(0.0092)
Other Members, HW	0.0009	−0.0034	−0.0042	−0.0007	−0.0088	−0.0051	0.0027	0.0053	−0.0132	−0.0127	−0.0092	−0.0095	−0.0111	−0.0121	−0.0134*	−0.0228	−0.0079	−0.0079	0.0046
	(0.0114)	(0.0108)	(0.0126)	(0.0129)	(0.0053)	(0.0057)	(0.0079)	(0.0083)	(0.0115)	(0.0110)	(0.0113)	(0.0092)	(0.0087)	(0.0085)	(0.0071)	(0.0173)	(0.0102)	(0.0091)	(0.0100)
EU Officials, DV	−0.0103	−0.0052	−0.0103*	−0.0108*	−0.0070	−0.0044	−0.0063	−0.0086*	−0.0070	−0.0084	−0.0094	−0.0063	−0.0056	−0.0051	−0.0051	−0.0130	−0.0080	−0.0085	−0.0081
	(0.0067)	(0.0050)	(0.0059)	(0.0061)	(0.0050)	(0.0043)	(0.0047)	(0.0047)	(0.0061)	(0.0058)	(0.0060)	(0.0058)	(0.0050)	(0.0059)	(0.0056)	(0.0101)	(0.0061)	(0.0053)	(0.0059)
ECB (F-G), DV	−0.0080	−0.0120	−0.0094	−0.0096	−0.0072	−0.0065	−0.0073	−0.0072	−0.0082	−0.0082	−0.0093	−0.0031	−0.0074	−0.0055	−0.0039	−0.0015	−0.0020	0.0050	0.0079
	(0.0102)	(0.0077)	(0.0099)	(0.0106)	(0.0083)	(0.0082)	(0.0100)	(0.0104)	(0.0118)	(0.0119)	(0.0121)	(0.0067)	(0.0049)	(0.0049)	(0.0047)	(0.0169)	(0.0116)	(0.0100)	(0.0110)
ECB (F-G), HW	0.0053	0.0123	0.0077	0.0076	0.0029	0.0039	0.0042	−0.0002	0.0212*	0.0200*	0.0203*	0.0075	0.0101	0.0143	0.0128	0.0303*	0.0220*	0.0162*	0.0152*
	(0.0113)	(0.0081)	(0.0084)	(0.0088)	(0.0061)	(0.0050)	(0.0059)	(0.0057)	(0.0109)	(0.0108)	(0.0107)	(0.0119)	(0.0084)	(0.0098)	(0.0089)	(0.0162)	(0.0096)	(0.0093)	(0.0089)
ECB (A-E), DV	0.0047	0.0047	0.0021	0.0021	0.0040	0.0035	0.0022	0.0027	0.0018	0.0015	−0.0010	−0.0018	−0.0011	0.0010	0.0029	−0.0047	−0.0010	−0.0013	−0.0029
	(0.0065)	(0.0048)	(0.0055)	(0.0090)	(0.0041)	(0.0037)	(0.0047)	(0.0049)	(0.0061)	(0.0058)	(0.0059)	(0.0050)	(0.0042)	(0.0042)	(0.0038)	(0.0090)	(0.0055)	(0.0049)	(0.0054)
ECB (A-E), HW	0.0103	0.0069	0.0119	0.0119	0.0007	0.0033	0.0022	0.0035	−0.0036	−0.0010	−0.0025	0.0054	0.0045	0.0042	0.0040	0.0192	0.0098	0.0104	0.0065
	(0.0099)	(0.0084)	(0.0090)	(0.0092)	(0.0062)	(0.0061)	(0.0071)	(0.0073)	(0.0085)	(0.0087)	(0.0100)	(0.0108)	(0.0075)	(0.0053)	(0.0050)	(0.0187)	(0.0104)	(0.0099)	(0.0100)
***GBY**, Full Sample: January 1, 2009 - August 12, 2011 (N=682)*																			
GER, DV		0.0036	0.0002	0.0002		−0.0069	−0.0051		0.0031	0.0021	0.0021		−0.0081*	−0.0055*	−0.0036*		0.0052	0.0020	0.0001
		(0.0039)	(0.0031)	(0.0022)		(0.0044)	(0.0030)		(0.0030)	(0.0017)	(0.0013)		(0.0030)	(0.0026)	(0.0018)		(0.0037)	(0.0025)	(0.0016)
GER, HW		0.0079*	0.0058*	0.0037*		0.0110*	0.0049*		0.0076*	0.0040*	0.0025*		0.0008	0.0009	−0.0004		0.0079*	0.0061*	0.0058*
		(0.0045)	(0.0028)	(0.0014)		(0.0046)	(0.0026)		(0.0025)	(0.0013)	(0.0011)		(0.0029)	(0.0022)	(0.0013)		(0.0029)	(0.0018)	(0.0013)
FRA, DV		0.0005	−0.0001	−0.0011		0.0003	−0.0049		−0.0023	−0.0026	0.0004		−0.0039	0.0004	0.0005		−0.0027	−0.0010	−0.0010
		(0.0041)	(0.0031)	(0.0015)		(0.0055)	(0.0024)		(0.0024)	(0.0012)	(0.0010)		(0.0034)	(0.0024)	(0.0016)		(0.0029)	(0.0019)	(0.0012)
PIIGS, DV		−0.0094*	−0.0007	−0.0004		−0.0036	−0.0013		0.0010	0.0028	0.0003		−0.0020	−0.0029	−0.0011		0.0021	0.0006	0.0016
		(0.0044)	(0.0029)	(0.0016)		(0.0048)	(0.0024)		(0.0028)	(0.0017)	(0.0012)		(0.0032)	(0.0029)	(0.0017)		(0.0035)	(0.0021)	(0.0014)
Other Members, DV		0.0057	−0.0028	0.0035		0.0035	−0.0060*		0.0004	0.0026*	0.0013		−0.0023	−0.0032	0.0009		−0.0001	0.0022	−0.0008
		(0.0055)	(0.0041)	(0.0018)		(0.0063)	(0.0027)		(0.0030)	(0.0015)	(0.0011)		(0.0034)	(0.0025)	(0.0022)		(0.0042)	(0.0028)	(0.0015)
Other Members, HW		−0.0029	−0.0020	−0.0008		0.0031	0.0017		0.0050	0.0002	0.0002		−0.0025	−0.0034	−0.0033		0.0010	0.0008	0.0008
		(0.0063)	(0.0043)	(0.0018)		(0.0060)	(0.0038)		(0.0032)	(0.0020)	(0.0015)		(0.0029)	(0.0025)	(0.0017)		(0.0050)	(0.0029)	(0.0017)
EU Officials, DV		−0.0059*	−0.0058*	0.0000		−0.0048	0.0000		−0.0028	−0.0020*	−0.0014*		−0.0027	0.0007	0.0004		−0.0036	−0.0030*	−0.0013
		(0.0029)	(0.0020)	(0.0014)		(0.0035)	(0.0018)		(0.0018)	(0.0010)	(0.0008)		(0.0020)	(0.0017)	(0.0012)		(0.0023)	(0.0015)	(0.0010)
ECB (F-G), DV		−0.0148*	−0.0044	−0.0040*		−0.0156*	−0.0044		−0.0057	−0.0023	−0.0005		−0.0030	−0.0038	−0.0026		−0.0066	−0.0035	−0.0009
		(0.0057)	(0.0039)	(0.0020)		(0.0078)	(0.0035)		(0.0037)	(0.0019)	(0.0017)		(0.0031)	(0.0025)	(0.0019)		(0.0073)	(0.0029)	(0.0025)
ECB (F-G), HW		0.0114*	0.0069*	0.0013		0.0034	0.0015		0.0021	0.0024*	0.0028*		0.0078*	0.0023	0.0031*		0.0077*	0.0059*	0.0025*
		(0.0039)	(0.0031)	(0.0017)		(0.0049)	(0.0024)		(0.0026)	(0.0013)	(0.0011)		(0.0032)	(0.0025)	(0.0017)		(0.0037)	(0.0024)	(0.0015)
ECB (A-E), DV		0.0023	0.0058	0.0017		0.0099*	0.0048*		0.0002	−0.0011	−0.0007		0.0014	0.0020	0.0015		−0.0025	−0.0063	0.0005
		(0.0027)	(0.0019)	(0.0012)		(0.0030)	(0.0016)		(0.0026)	(0.0010)	(0.0008)		(0.0018)	(0.0019)	(0.0010)		(0.0020)	(0.0015)	(0.0010)
ECB (A-E), HW		−0.0088	−0.0044	0.0009		−0.0111*	−0.0059*		−0.0047*	−0.0042*	−0.0001		0.0035	0.0036	−0.0005		0.0024	0.0007	−0.0008
		(0.0042)	(0.0031)	(0.0019)		(0.0049)	(0.0028)		(0.0028)	(0.0016)	(0.0015)		(0.0028)	(0.0026)	(0.0018)		(0.0026)	(0.0025)	(0.0027)

Notes: The table reports the daily reaction of sovereign CDS Premia and bond yields (GBY) to the communication variables. Standard errors are shown in brackets below the coefficients. * indicates significance at the 90% level or greater.
a The Portuguese sample for government bonds with 30 years maturity starts on May 27, 2009.

4 Cities and the Structure of Social Interactions: Evidence from Mobile Phone Data*

4.1 Introduction

Social interactions lie at the nexus of two key themes in economics: sustained aggregate growth and the concentration of economic activity in cities. In a widely cited paper, Robert Lucas (1988) models human capital accumulation as main driver behind economic development. Interpersonal exchange is pivotal to the narrative of his framework, with Lucas (1988, p. 19) defining "human capital accumulation [a]s a *social activity*, involving groups of people". Through this social learning process, human capital not only provides an internal value to its owner but also exerts a positive externality on peers, which fosters the creation of new ideas and with it sustained development. In reference to urban theorist Jane Jacobs (1969), Lucas (1988) suggests that these externalities are especially prevalent in cities, which consequentially act as engines of growth. This notion reflects one of the classic agglomeration forces described by Alfred Marshall (1890), who argues that the dense concentration in cities facilitates the flow of information and knowledge, since social interactions diminish over space. Although social interactions are considered to play a decisive role for the aggregate dynamic and spatial organisation of the economy, empirical work uncovering the alleged micro-mechanisms has remained fragmentary at best.

This paper studies the relation between spatial structure and social interactions in order to test fundamental assumptions underlying the agglomeration forces discussed in the literature. The analysis builds on anonymised mobile phone calls between June 2015 and May 2016. This allows us to examine the interplay between local characteristics and social interactions as we not only observe comprehensive communication patterns but also location information derived from transmitting antennas and billing data. Based on this rich dataset and concepts from the network literature (e.g. Jackson, 2008), we investigate three main questions. *First*, how does geographical distance impact social interactions? *Second*, what is the relation between population density and the size of an individual's social network? *Third*, does population density affect the quality / efficiency of social interactions in terms of matching quality, clustering and network perimeter? To answer these questions we employ link formation models in the spirit of Graham (2014) and additionally estimate the impact of population density on various micro-level network measures.

*This chapter is joint work with Maximilian von Ehrlich.

The sorting of individuals with specific characteristics can distort the results of both approaches. We therefore base our inference on individuals who change their place of residence (i.e. "movers") to back out time constant unobservables and correctly identify the role of distance as well as density-related externalities.

We show that distance is highly detrimental to social interactions, despite epoch-making progress in communication technologies. Contrary to the conventional view, this does not translate into larger networks in cities compared to the periphery. Density-related externalities rather arise in terms of network efficiency, namely better matching quality, lower clustering, and smaller distance costs. We are not aware of any study that has delivered comparable evidence on regional differences in both network size and network efficiency. Below, we discuss the main findings with reference to the related literature.

4.1.1 Related Literature

Social Interactions and Distance. Models that incorporate knowledge and learning spillovers as an agglomeration force typically assume that distance is costly to social interactions (e.g. Glaeser, 1999). The widespread adoption of information and telecommunication technologies popularised the "death-of-distance" argument (e.g. Cairncross, 2001), which raises the intriguing question of whether these technologies will fundamentally change the structure of cities (see Ioannides et al., 2008) or even make them obsolete (see Gaspar and Glaeser, 1998). We demonstrate that the social interactions recorded by mobile phones are surprisingly localised, with more than 60 percent of ties occurring between individuals that reside within less than 10 km distance of each other. Importantly, we aim for a causal interpretation and therefore estimate a network formation model based on movers. This novel analysis confirms that distance is highly detrimental to forming and maintaining social ties. A recent study by Levy and Goldenberg (2014) uncovers similar patterns for email traffic and online social media contacts. We interpret this as solid evidence against the death-of-distance hypothesis in the social exchange context.

Quantity of Social Interactions. Building on the assumption that distance is costly to social interactions, numerous micro-founded models of urban agglomeration economies have been developed (cf. Duranton and Puga, 2004). One body of literature focuses on the claim that the quantity of social interactions increases with local population density. Glaeser (1999) formalises the classic idea of Marshall (1890) that individuals acquire skills by interacting with each other. As cities are more densely populated than the hinterland, they facilitate more meetings in his framework and thus accelerate the social learning process. Another example is that of Sato and Zenou (2015), who model social interactions and their impact on employment outcomes. They propose that city residents maintain larger networks than rural dwellers, enabling them to acquire more information on the labour market, which reduces job search frictions and unemployment. Two empirical studies support the hypothesis that cities facilitate interpersonal exchange. Charlot and Duranton (2004) use survey data on workplace communication in France, while Schläpfer et al. (2014) examine mobile phone records for Portugal. Both studies find that the average number of (unique) social interactions increases with population size. However, neither can plausibly isolate the causal impact of density from non-random sorting, as the first paper relies on cross-sectional data and the second paper narrows down to a descriptive analysis. Burley (2015) studies the German Socio-Economic Panel and finds that population density is only positively correlated with an index of social interactions, as long as person specific characteristics are ignored.[1] Our results reinforce this finding: we also show that the positive effect of cities compared to the hinterland vanishes, once targeted sorting of individuals is accounted for. Given the pattern emerging from these four studies, the claim that cities produce more social contacts than the periphery seems unfounded.[2]

Efficiency of Social Interactions – Matching Quality. Another strand of literature argues that cities do not necessarily increase the quantity of social interactions but rather improve their quality / efficiency. In the model of Berliant, Reed and Wang (2006), agents possess differentiated types of knowledge. The effect of cities on the number of social interactions then becomes twofold, as densely populated areas increase the number of random meetings but also make agents more selective regarding matching quality. Hence, while cities do not necessarily affect the number of social interactions, Berliant, Reed and Wang (2006) show that their quality in terms of knowledge complementarity should improve with increasing population density. With the aim of providing an empirical test for the matching channel, Abel and Deitz (2015) study data on job searching of college graduates. They find that larger and thicker labour markets indeed improve the matching between job advertisements and applicants' qualifications. To the best of our knowledge, no study to date has assessed this hypothesis with respect to social interactions. We formulate two tests, one relying on a network formation model, and the other analysing the social adjustment process among movers. Both approaches indicate that urban dwellers indeed benefit from higher quality matches compared to people living in the hinterland.

Efficiency of Social Interactions – Clustering. Borrowing from the network literature, the level of clustering / triangular relations is an additional dimension of efficiency that is sometimes assumed to vary regionally. Granovetter (1973) famously argues that weak ties are often more valuable in terms of information provision than strong ties. He formally defines a weak tie as a social relation between two agents who have no overlap in their personal networks. In contrast, strong ties involve triangular relations that bring about redundancies in the process of information diffusion. Sato and Zenou (2015) claim that cities not only increase the number of social interactions – as discussed above – but also give rise to a disproportionally high number of weak tie relations that are more valuable in the job market. We calculate the clustering coefficient (i.e. the share of triangular relations) of each agent in the data set and test whether the level of clustering systematically varies with population density. We find that personal

[1] Based on US survey data, Brueckner and Largey (2008) also examine population density and social interactions obtaining consistently negative correlations. These findings are at odds with the other studies, as they suggest that cities are too dense from a social interaction point of view.

[2] Other factors that have been shown to impact the level of social interactions are homeownership (e.g. Hilber, 2010) and racial fragmentation (e.g. Alesina and La Ferrara, 2000; Brueckner and Largey, 2008).

networks in cities indeed tend to be characterised by lower levels of clustering and thus have a higher fraction of weak ties. This finding suggests that cities may facilitate the diffusion of information, although the average number of social interactions is not necessarily larger than in more sparsely populated areas.

The following section elaborates on the main concepts. Section 3 introduces the data used in the empirical analysis. Section 4 explains the empirical strategy. Section 5 discusses the results. Section 6 concludes.

4.2 Cities and Social Interactions: Main Concepts

We consider a directed network with N nodes each representing a unique phone customer which we denote by $i \in \mathcal{N} = \{1, ..., N\}$. Each customer has a place of residence, r, which is assigned either on the municipality or postcode level. The number of nodes at location r is N_r, and so with R denoting the total number of different residences, $N = \sum_r N_r$ holds. Finally, $\mathcal{R}_r$ is the set of individuals living in location r.

A link between nodes i and j is denoted by $g_{ij} = 1$, while the absence of a link is marked as $g_{ij} = 0$. The network can then be characterised by a pair $(\mathcal{N}, \mathcal{G})$ where $\mathcal{G} = [g_{ij}]$ is a $N \times N$ adjacency matrix. As in Graham (2014), we assume that rational agents i and j establish a link if the net surplus from doing so is positive. This yields a random utility model of the form

$$g_{ij} = \mathbf{1}\left(X'_{ij}\eta + \nu_i + \nu_j + U_{ij} \geq 0\right), \tag{4.1}$$

where X_{ij} is a vector of dyad attributes (i.e. pair specific characteristics), ν_i and ν_j denote agent specific characteristics, and U_{ij} is a randomly distributed component of link surplus. We are particularly interested in the role of dyad attributes, which we divide into three groups: geographical distance or travel time (T_{ij}), the number of friends i and j share ($F_{ij} = \sum_{k=1}^{N} g_{ik}g_{jk}$), and matching ($m(\nu_i, \nu_j, \delta)$). As defined in this study, higher levels of $m(\cdot)$ increase link surplus, which is why we refer to it as matching *quality*. Importantly, it absorbs the spread between Q individual characteristics of agent i and j, $|\nu_i - \nu_j|$, which – depending on the specific attribute $q \in Q$ – may be positively (i.e. $\delta_q > 0$) or negatively correlated (i.e. $\delta_q < 0$) with matching quality. Based on these considerations we define the vector X_{ij} as

$$X'_{ij}\eta = \eta_1 \cdot T_{ij} + \eta_2 \cdot F_{ij}(\mathcal{G}) + \eta_3 \cdot m(\nu_i, \nu_j, \delta). \tag{4.2}$$

If link-surplus is indeed a function of these three dyad-specific factors, this may have important consequences for the network topography across rural and urban areas. Provided that distance is costly for social interactions, regional differences in population density may determine the *size* of an agent's social network. This is of interest, because social contacts can foster the diffusion of information, promote trust and thereby lower transaction costs, and facilitate learning from peers (Jackson, 2014; Granovetter, 2005; Gui and Sugden, 2005) in addition to having intrinsic value for a person's well-being (Burt, 1987). We further focus on matching and common friends (or clustering), as they have implications for a *network's efficiency*: Matching reflects the quality of a specific contact, which incorporates various dimensions such as productivity enhancing skill complementarity, or shared interests (e.g. Berliant, Reed and Wang, 2006). Clustering governs the informational value of a link, since contacts who share a common friend introduce redundancies and are therefore less valuable in the information diffusion process (Granovetter, 1973). In return, sharing mutual contacts fosters cooperative and pro-social behaviour, because the triangular relation can act as a reputational control and retaliation device (Jackson, 2014).

Network Size and Degree Centrality. We first discuss the relation between population density and the size of an individuals social network, which we measure based on *degree centrality*, formally defined as

$$D_i(\mathcal{G}) = \#\{j : g_{ij} = 1\}. \tag{4.3}$$

The degree yields the number of distinct peers with whom agent i interacts socially and therefore the number of sources that potentially forward valuable information. Typically, urban economic theory (e.g. Glaeser, 1999; Sato and Zenou, 2015) presumes that cities provide a favourable environment for social interactions and support larger network sizes, as they are more densely populated than rural communities. The underlying argument hinges on the assumption that the costs of social interactions increases with distance. Let us abstract from the matching spread, $m(\nu_i, \nu_j, \delta)$, as well as triangular ties, $F_{ij}(\mathcal{G})$, and focus on the relationship between distance and population density. A stylised argument is as follows: On weekdays an agent i needs to keep her travelling costs low, and she therefore has random encounters only with people in her municipality, $j \in \mathcal{R}_r$. At the weekend, however, the radius of the agent's actions is unbounded, so that she might form ties with people living outside her place of residence, $k \notin \mathcal{R}_r$. Since people spend more time in their residence's vicinity, the probability to acquire social contacts among neighbours, $P_r = P(g_{i,j\in\mathcal{R}_r} = 1)$, is larger than for the rest of the population, that is $P_r > P_{-r} = P(g_{i,k\notin\mathcal{R}_r} = 1)$. In the outlined example, the size of a person's social network positively depends on the population living in the neighbourhood, N_r, so that cities support a larger degree than rural municipalities, i.e.

$$D_i = N_r \cdot P_r + (N - N_r) \cdot P_{-r} \qquad \text{with } \frac{\partial D_i}{\partial N_r} > 0. \tag{4.4}$$

While this intuitive rationale is appealing, it may be challenged from two angles, namely from biological/anthropological and search strategic points of view.

In evolutionary biology, Dunbar (1992, 1998) has famously advocated and popularised the *social brain hypothesis*. It challenges the field's traditionally dominant view that brains evolved to address ecological problem-solving tasks, such as foraging. Instead the social brain hypothesis attributes the growth in primates' brain sizes to the computational demands of their increasingly complex social systems. Indeed, empirical analyses reveal a close relation between neocortex volume and mean social group size among primates. This has been interpreted as evidence that there is a species-specific upper limit to group size that is set purely by cognitive constraints. For humans, Dunbar (1993) calculates the upper limit to lie between 100 and 230 social contacts, citing anthropological studies on modern hunter-gatherer societies as evidence that support his prediction. Recent studies explore this hypothesis by analysing patterns among adults' prefrontal cortex volume, cognitive ability, and the size of their social networks (Stiller and Dunbar, 2007; Powell et al., 2012) or by exploiting social media user statistics (Dunbar, 2015). In consideration of the manifold results corroborating the social brain hypothesis, one may note that the size of a person's network is fundamentally restricted by congenital factors. Because the population of practically all Swiss municipalities exceeds the limit for network size as calculated by Dunbar (1993), the number of social interactions may be independent of regional differences in population density.

In equation (4.4) a random encounter between two persons is equivalent to establishing a link. We now add another layer: After meeting a potential contact, agents can either accept or reject to form a link based on the other person's characteristics. Since forming a link consumes time and cognitive capacity, this introduces a quality-quantity trade-off. Consequently, it may be optimal to reject some potential contacts to wait for a better match (see Berliant, Reed and Wang, 2006). Hence, from a *search strategic* perspective, higher population density may impact network size only marginally, but it may allow for higher selectivity along dyad-specific characteristics. This has important consequences for the analysis of social networks across different regions. Even if densely populated areas improve social networks, the advantages may not be in terms of size but in terms of efficiency. In this respect, *matching quality* between agents i and j, $m(\nu_i, \nu_j, \delta)$, is of key interest, as it determines how well their interests correspond or how fruitful the intellectual exchange between them is. Once we add the strategic component of weighing between quality and quantity to the above mechanics, we would expect a positive effect of population density on matching quality, or network size, or both.

Perimeter of Social Interactions and the Within-Degree. The previous line of reasoning also has implications for the perimeter of a person's network. Essentially, the travel time between two agents can be considered one dimension of matching quality. Assuming that distance is costly when maintaining a link, one would rather form a tie with a neighbour than with an identical person living far away. Following Berliant, Reed and Wang (2006) therefore implies that high-density locations allow people to be more selective regarding the travel distance to their contacts, so that they can minimise travel costs induced through social interactions. Put differently, one may expect that urban dwellers can recruit their contacts within a narrower perimeter, since densely populated cities make high quality matches in a small area possible. In contrast, people in rural areas face a much tighter choice in their neighbourhood, thus they likely prefer to widen the search radius with the objective of improving their network's quality. To analyse these claims, we examine the degree within an individual's neighbourhood or *within-degree*, formally defined as

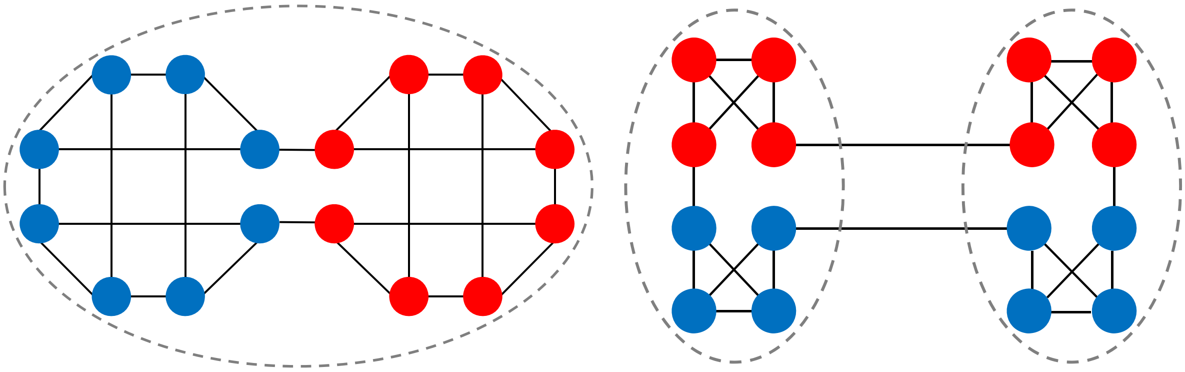
$$DW_i^r(\mathcal{G}) = \#\{i, j \in \mathcal{R}_r : g_{ij} = 1\}. \tag{4.5}$$

Of course, negligible distance costs would wipe out any differences between cities and rural areas. Costs related to distance may indeed be of secondary importance for a person with naturally few social interactions, whereas highly sociable persons may benefit more from densely populated areas, as recently formalised in a paper by Helsley and Zenou (2014). Consequently, differences in network size may simply be observable due to the sorting of highly sociable types into cities, because they gain disproportionally from low distance costs per contact.

Clustering. In a last step, we discuss regional differences in population density and their implications for clustering in social networks. Clustering is an important network characteristic as it can provide insights into reciprocity and information diffusion. On the one hand, high clustering strengthens reputational concerns and with it the enforcement of social norms and cooperation (e.g. Ali and Miller, 2009), or risk-sharing (e.g. Ambrus, Mobius and Szeidl, 2014). On the other hand, Granovetter (1973) highlights the importance of local bridges for passing on information. An individual with high clustering introduces redundancies in the network, which are inefficient in terms of information diffusion. The *clustering coefficient* for node i is given by

$$C_i = \frac{\sum_{j,k\, j\neq k} g_{jk}}{\sum_{j,k,j\neq k} g_{ij} g_{ik}}, \tag{4.6}$$

and measures whether an individual's contacts form a tightly knit group ($C_i \to 1$) or are completely separate from each other ($C_i \to 0$). How does population density relate to clustering? There are two potential channels, one mechanical and the other as a consequence of differing preferences. Figure 4.1 illustrates the mechanical rationale: Panel (a) shows a city with 16 agents, eight blue and eight red. All agents socially interact with three other agents, preferably of the same type. Panel (b) represents a peripheral region with lower population density, therefore the 16 agents are equally split between two municipalities. As in the city, all individuals have a degree of three. Importantly, travelling between the two municipalities is costly, therefore agents prefer to form links with their neighbours. Since every person has only three neighbours of the same type, the network ends up tightly clustered. In contrast, the city makes clustering less likely, because each urbanite can choose among seven agents of the same colour. In the way the example is drawn, the average clustering in the city equals 0, while it amounts to 0.5 in the periphery. As a consequence, the average path length in the city (=2.73) is lower than in the periphery (=3.2), which accelerates the diffusion of information. Thus, low density locations should tend to display higher clustering, simply because residents of these areas face a substantially smaller set of suitable contacts in their direct vicinity compared to urban dwellers. In addition to this purely probabilistic relation between density and clustering, preferences for forming links with friends of friends, $F_{ij}(\mathcal{G})$, could be different in cities than in rural areas. Agents face a trade-



(a) **City:** Average Degree=3, Matching Rate=0.833, Average Clustering=0, Average Path Length=2.73

(b) **Periphery:** Average Degree=3, Matching Rate=0.833, Average Clustering=0.5, Average Path Length=3.2

Figure 4.1: Clustering in Cities and the Periphery – An Illustrative Example

off in terms of efficient information exchange (i.e. low clustering) and benefits due to stronger reciprocity (i.e. high clustering). The optimal balance may vary regionally due to factors that assign a higher weight to reciprocity or information diffusion. For instance, high quality local institutions may substitute for reciprocity or a dynamic labour market environment may support the value of information diffusion. In addition, clusters may facilitate simultaneous interactions with multiple persons, allowing for larger networks given a certain time constraint. If people living in rural neighbourhoods have more geographically dispersed social networks, clusters of friends could be a strategy to mitigate travel costs. Finally, it has been documented that people living in peripheral areas have a higher proportion of kin ties than urban dwellers (Fischer, 1982). A preference for spending time with relatives most likely increases the clustering in an individual's network as relatives inevitably have an overlap in their circle of acquaintances.

4.3 Data

The main dataset used in this paper is provided by Switzerland's largest telecommunications operator, *Swisscom AG*, whose market share is 55% for mobile phones and 60% for landlines (ComCom, 2015). The data comprises comprehensive *call detail records (CDR)* of all outgoing calls made by the operator's customers between June 2015 and May 2016. The CDRs include the anonymised phone number of caller and callee, a date and time stamp, a binary indicator for private and business customers, a code for the type of interaction recorded (e.g. call, SMS, MMS), the duration of calls in seconds, and the x-y-coordinates of the caller's main transmitting antenna. We observe finely grained information on about 15 million calls and text messages per day, covering 7.2 million phones, of which 2.4 million are private mobile devices.[3] Along with the anonymised CDRs, the operator also provided monthly updated *customer information* including billing address, language of correspondence (German, French, Italian, English), age, and gender.

[3]More specifically, the data set covers 2.4 million private mobile phones, 1.9 million private land lines, 1.1 million corporate mobile phones, and 1.8 million corporate landlines.

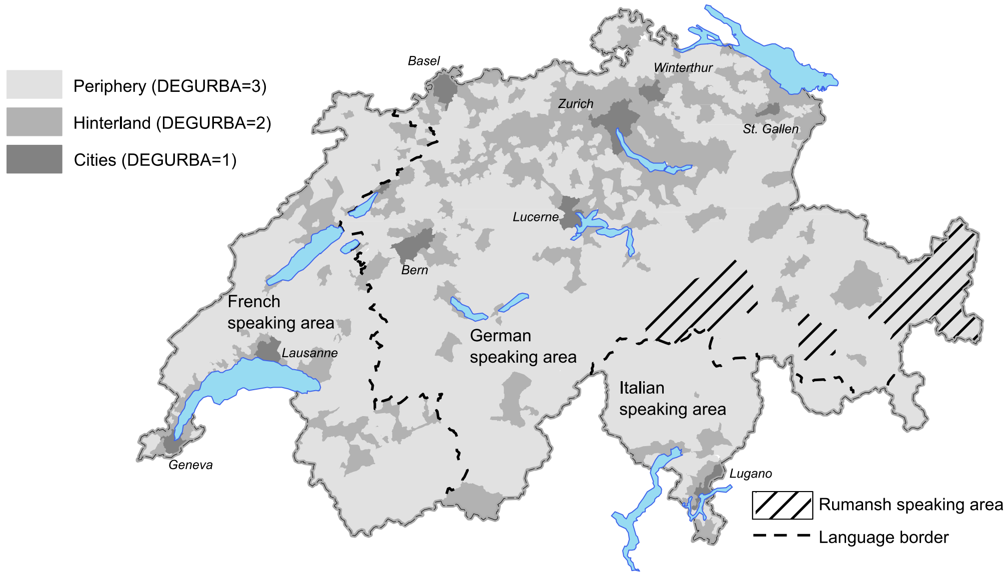


Figure 4.2: Degree of Urbanisation – Cities, Hinterland and Periphery

Table 4.1 summarises the socio-demographic characteristics of mobile phone customers in our sample, while Table A.3 shows correlations between census data and our customer statistics for various subpopulations. This comparison suggests that the data at hand is highly representative of the Swiss population.

The phone data are complemented by various municipal statistics for 2014 provided by the Federal Statistical Office (FSO), including population figures and the degree of urbanisation as classified by EUROSTAT.[4] Figure 4.2 shows the regional variation in urbanisation based on the aforementioned measure. We also compute geographical distances between pairs of municipalities and pairs of postcodes using ArcGIS software and shape files for administrative boundaries published by the Federal Office of Topography. Car driving distances between centroids of municipalities and postcode areas were kindly provided by the company *search.ch*. Descriptive statistics for municipalities and postcodes are shown in Table A.1 in the appendix.

The anonymity of Swisscom customers was guaranteed at all steps of the analysis. We never dealt with or had access to uncensored data. A data security specialist retrieved the CDRs from the operator's database and anonymised the telephone numbers using a 64-bit hash algorithm that preserved the international and local area codes. He further removed columns with information on the transmitting antenna before making the data available. Once the anonymised data were copied to a fully sealed and encrypted Swisscom workstation, we ran the analysis on site. To utilise information on the transmitting antenna we passed location scripts to Swisscom personnel who executed them for us.

Our primary aim is to observe social networks, but not every instance of phone activity reflects a social interaction in the narrower sense so that the dataset needs to be cleaned befo-

[4] See `http://ec.europa.eu/eurostat/ramon/miscellaneous/index.cfm?TargetUrl=DSP_DEGURBA` (last access: 01.06.2016) for more information on the EUROSTAT DEGURBA measure.

Table 4.1: Descriptive Statistics, Private Mobile Phone Customers

	Mean	SD	N	Min	Max
Phone Usage, June 2015 – May 2016 (pooled)					
Number of Calls	111.781	109.599	10 399 549	1	10 113
Duration (Minutes)	254.970	295.609	10 399 549	2	3359
Network Characteristics, June 2015 – May 2016 (pooled)					
Degree Centrality	9.202	7.910	10 399 549	1	470
Within-Degree (15 Min. Radius)	7.067	7.231	10 399 549	0	221
Clustering Coefficient	0.092	0.132	10 248 923	0	1
Sociodemographics					
Age	34.964	13.561	866 646	20	60
Female	0.522	–	866 646	0	1
Language: German	0.681	–	866 646	0	1
Language: French	0.270	–	866 646	0	1
Language: Italian	0.043	–	866 646	0	1
Language: English	0.006	–	866 646	0	1

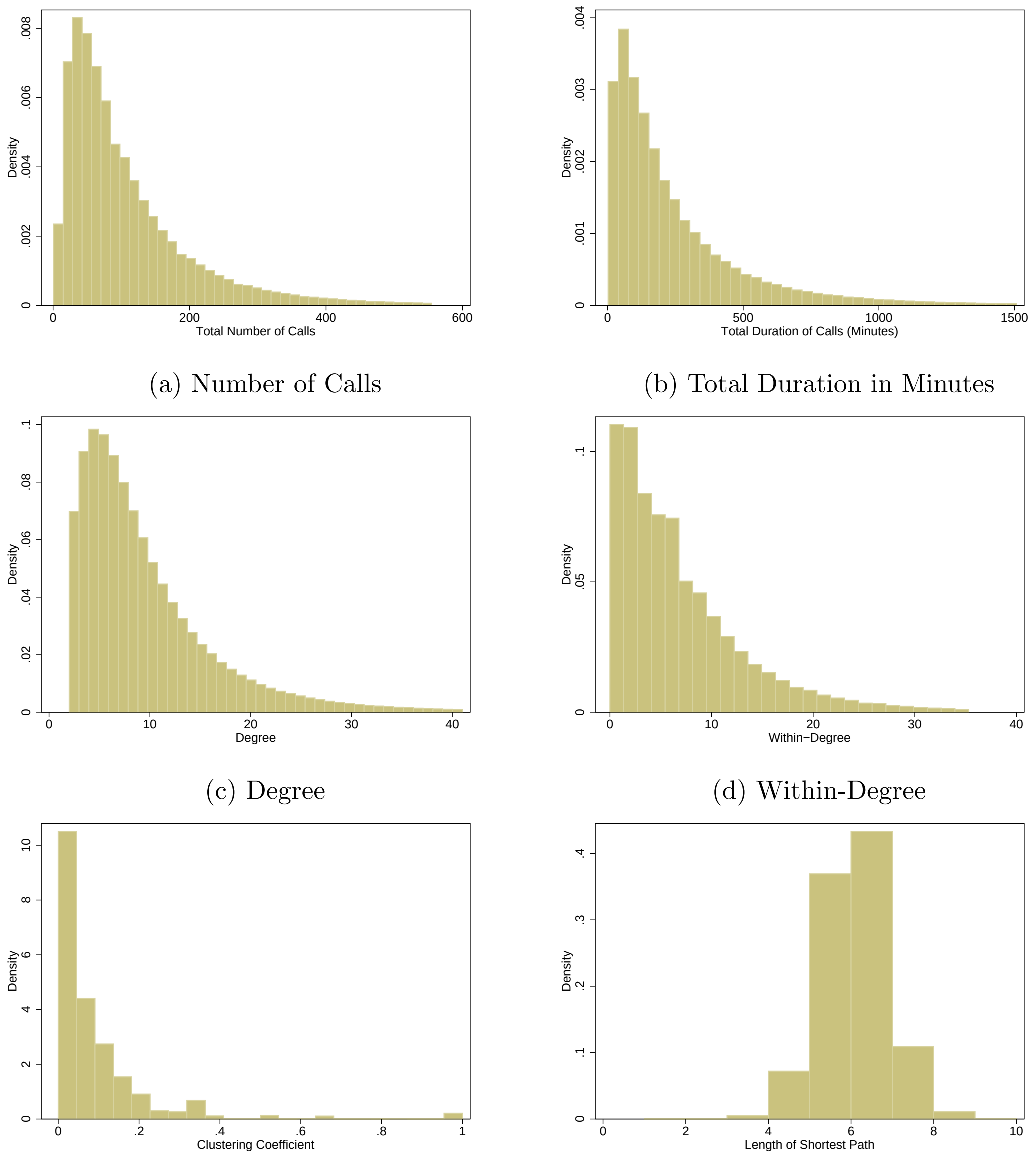
Notes: The table is based on the subsample of customers with phone activity in all 12 months, which we also use in the main analysis. Further filters as described in section 4.3. Phone usage statistics include in- and outgoing calls. The *within-degree* measures network size within a radius of 15 minutes around an agent's residence.

rehand (for a discussion see Blondel, Decuyper and Krings, 2015). In our benchmark analysis, we filter the data as follows: *First*, we restrict the analysis to *calls* between mobile phones. Mobile phones are personal objects and are thus representative of the social network of a single person, while calls from fixed phones possibly resemble overlapping social networks as they are usually shared by multiple users. For the same reason, all results are based on customers who have registered only one active mobile phone number. Customers with multiple active numbers typically include corporate customers, as well as parents acting as invoice recipients for their children. *Second*, we limit the analysis to outgoing calls in order to cover intra-operator and inter-operator activity equally well and to filter out promotional calls by call centres. *Third*, calls with a duration of less than 10 seconds are considered accidental and are therefore excluded from the analysis. *Fourth*, we drop mobile phone numbers that display implausibly low or high monthly usage statistics, with a minimum threshold of 1 minute and a maximum threshold of 56 hours per month, respectively. This removes practically inactive numbers as well as phones used for commercial purposes. *Fifth*, the analysis is limited to *private mobile phones*, so that daily business calls between corporate customers do not create noise in our measures. *Sixth*, some measures require address information for both caller and callee such that inter-operator calls cannot be used in all steps of the analysis. Measures requiring location information for the callee are therefore based on intra-operator calls only, which we weight according to the operator's market share at the callee's billing address. *Finally*, we only use the first 28 days of each month to make the data easily comparable across different time periods.

These steps eliminate approximately 60 percent of the calls recorded for private customers, leaving us with around 60 million calls per month that amount to a total duration of 200 million minutes (for details see Table A.2 in the appendix). We have performed sensitivity checks with regards to all above mentioned dimensions to ensure that our results are robust.

4.3.1 Descriptive Statistics on Phone Usage and the Social Network

Table 4.1 shows summary statistics on the mobile phone usage of customers aged 15 to 64 for the filtered data set.[5] The average private mobile-phone users makes about three calls per day with a cumulative duration of nine minutes. Figures 4.3a and 4.3b further show that the distributions are markedly right-skewed.



(a) Number of Calls

(b) Total Duration in Minutes

(c) Degree

(d) Within-Degree

(e) Clustering Coefficient

(f) Dyad Distances

Figure 4.3: Histograms of Phone Usage Statistics & Network Characteristics for June 2015.

The network of private mobile phone interactions uncovered by the data exhibits characteristic features of other socially generated networks documented in the literature (Jackson and Rogers, 2007; Watts, 1999): Small diameter and short average path length between pairs, "fat

[5] Due to privacy concerns, we worked with decimal age-brackets. This means that a customer aged 24 was assigned to the 20-bracket, while a customer aged 25 belongs to the 30-bracket.

tails" in the degree distribution, and substantial clustering.

To gain insights into the diameter and the average path length, we randomly select 100 individuals and calculate the length of the shortest paths connecting every other private mobile phone users in the data. The mean path length in the sample is 5.6, with the longest path having a length of 12 (1 out of 246 mio.); the histogram plotted in Figure 4.3f reveals that 88 percent of dyads are separated by 6 or fewer links. This fits strikingly well with the "small-world"-hypothesis first formulated by Milgram (1967) and the early empirical evidence based on a chain letter experiment conducted by Travers and Milgram (1969).

As Figure 4.3c illustrates, the degree distribution in our social network exhibits "fat tails", so that there are more nodes with relatively high and low degrees, and fewer nodes with medium degrees, than one would find in a network where links are formed uniformly. The average degree in our monthly data is approximately 9, with the vast majority having a degree below 20 and some hub-agents reaching network sizes of 100 links or more. As reported in other studies on social networks, the probability distribution is well fitted ($R^2 = 0.92$) by a power-distribution, $P(D) = cD^{-\varphi}$, with parameter estimates of $\hat{\varphi} = 3.86$ and $\hat{c} = 5.96$.

The clustering coefficient, which measures the tendency of linked nodes to have common neighbours, is, on average, 0.092, with more than 75 percent of the individuals in the dataset having a non-zero clustering coefficient (see Figure 4.3e). Considering the low density of our network (≈ 0.00002), the observed clustering is evidently larger than in a benchmark network where links would have been generated by an independent random process.

4.4 Identification

In order to analyse the impact of geography and location characteristics on the structure of social interactions we conduct two complementary identification strategies. The first aims to identify factors that predict the likelihood of individuals i and j forming a link and is referred to as *network formation*. In particular, this approach allows us to study the effects of distance between i's and j's place of residence on the probability that they form a link. It further enables inference on the preference for triadic relations. The presence of network overlap may influence the likelihood that i and j establish a link as the returns may be higher or lower if it involves mutual contacts. Moreover, we study whether homophily – the process of matching on common characteristics – is prevalent in the data.

The second approach, to which we refer as *network topography*, estimates the effect of local characteristics on individual-level network measures. This relates to the equilibrium outcome of network formation at different places and allows us to examine the impact of location specific attributes on social networks.

Sorting of individuals with specific characteristics can affect the results of both approaches. As we observe the full social network for one year we can exploit changes in the address of mobile phone customers; this enables us to isolate the role of systematic sorting and to obtain causal estimates of geography and population density on network formation and network topography.

4.4.1 Network Formation

We observe the social network's adjacency matrix $\mathcal{G}_t = [g_{ij,t}]$ in each month $t \in \{1, ..., 12\}$. Following Graham (2014), we specify the probability that two nodes i and j form a link as

$$g_{ij,t} = \mathbf{1}(\beta g_{ij,t-1} + T'_{ij,t}\eta_1 + F'_{ij,t-1}\eta_2 + Z'_{ij}\rho + \phi_1 D_i + \phi_2 D_j + m(\xi_i, \xi_j, \delta) + U_{ij,t} \geq 0) \quad (4.7)$$

where vector $T_{ij,t}$ measures the distance between agent i and j based on their residence and workplace, $F_{ij,t-1}$ is a vector of dummies to discretise the number of contacts agents i and j share in common, Z_{ij} is a vector of dyad-specific time invariant covariates, D_i and D_j capture static differences in sociability based on both parties' logarithmised long-term degree, and $m(\xi_i, \xi_j, \delta)$ is a symmetric matching function of unobserved node specific heterogeneity.[6] We assume that $U_{ij,t}$ is independent and identically distributed and has mean zero such that we can estimate a linear probability model of the form:

$$g_{ij,t} = \beta g_{ij,t-1} + T'_{ij,t}\eta_1 + F'_{ij,t-1}\eta_2 + Z'_{ij}\rho + \phi_1 D_i + \phi_2 D_j + m(\xi_i, \xi_j, \delta) + U_{ij,t}. \quad (4.8)$$

In particular, the distance measures represented by vector $T_{ij,t}$ comprise the log travel time between agents i's and j's residence as well as a dummy for same workplace. The latter equals one if they predominantly use antennas within the same 5 km radius during business hours. We discretise the number of common friends, such that we obtain two dummy variables contained in $F_{ij,t-1}$: The first indicator equals one, if agents i and j share at least one common social contact, while the second indicators equals one if agents i and j share at least two common contacts.[7] The dyad-specific covariates in vector Z_{ij} include three dummy variables indicating same age, same gender and same language.

The model in (4.8) also accounts for matching based on unobservables as reflected by $m(\xi_i, \xi_j, \delta)$. Those that favourably match in terms of unobservable characteristics ξ feature a higher likelihood to form a link. These unobservables may bias our estimates of the cross sectional model in (4.8). If individuals with common unobservable attributes are more likely to cluster regionally and thus live closer together, our distance measure will be negatively correlated with the error term. A within-transformation will take out time invariant factors that affect the matching quality, i.e.

$$\begin{aligned} g_{ij,t} - \bar{g}_{ij} &= \beta(g_{ij,t-1} - \bar{g}_{ij}) + (T_{ij,t} - \bar{T}_{ij,t})'\eta_1 + (F_{ij,t-1} - \bar{F}_{ij})'\eta_2 + U_{ij,t} - \bar{U}_{ij}, \quad \text{or} \\ \ddot{g}_{ij,t} &= \beta \ddot{g}_{ij,t-1} + \ddot{T}_{ij,t}\eta_1 + \ddot{F}'_{ij,t-1}\eta_2 + \ddot{U}_{ij,t}. \end{aligned} \quad (4.9)$$

[6] Note that the number of mutual contacts, $F_{ij,t-1}$, enters with a lag. This implies that agents form/maintain/dissolve links myopically, as if all features of the previous period's network remain fixed. Assuming this structure, eliminates contemporaneous feedback, which can problematic for inference (see Graham, 2014).

[7] We discretise the number of mutual friends, because the continuous measure yields imprecise (yet significant) estimates. We also tried specifications with three or more common friends dummies, which turned out insignificant.

In equation (4.9) the transformed residual, $\ddot{U}_{ij,t}$, is necessarily correlated with the lagged dependent variable, $\ddot{g}_{ij,t-1}$, because both are a function of $\bar{U}_{ij}$. Therefore, OLS estimates of equation (4.9) are not consistent for the parameters of interest. We therefore follow Angrist and Pischke (2009) and estimate models including the lagged dependent variable but not the fixed effects, as in equation (4.10a.), and then compare the results to estimates obtained from a fixed effect regression without the dynamic component, as in equation (4.10b.):

$$\begin{aligned} &\text{a.}\quad g_{ij,t} = \beta g_{ij,t-1} + T'_{ij,t}\eta_1 + F'_{ij,t-1}\eta_2 + Z'_{ij}\rho + \phi_1 D_i + \phi_2 D_j + U_{ij,t} \\ &\text{b.}\quad \ddot{g}_{ij,t} = \ddot{T}_{ij,t}\eta_1 + \ddot{F}'_{ij,t-1}\eta_2 + \ddot{U}_{ij,t}. \end{aligned} \tag{4.10}$$

These two models have a useful bracketing property, that bounds the causal effect of interest. With respect to the geographical distance between two agents, we expect that the fixed effect estimates are upwardly biased, while the lagged dependent model yields a downwardly biased estimate (see Angrist and Pischke, 2009, p.245–247). We also estimate equation (4.10a.) within a Logit framework in order to account for the dichotomous nature of the data.

A practical issue that arises with estimating the outlined network formation models is the size of the adjacency matrix that potentially includes $(2 \cdot 10^6)^2$ unique pairs of agents. It is neither computationally feasible to estimate the models based on all these pairs nor necessary for obtaining consistent estimates of the parameters of interest as is shown by Manski and Lerman (1977), and Cosslett (1981). Since we have complete information on the network we can use a stratified sample and adjust the estimates with the respective sampling weights. Our choice-based sample results from an endogenous stratified sampling scheme where each stratum is defined according to the individual responses, that is the binary values taken by the response variable $g_{ij,t}$.[8] This sampling structure requires the availability of prior information on the marginal response probabilities which is in our setting available due to the full observation of $\mathcal{G}_t$.

4.4.2 Network Topography

We estimate the effect of location characteristics on the individual-level network measures formally defined in section 4.2: degree, within-degree, and clustering coefficient. Below, we lay out the estimation strategy for degree centrality noting that specifications for all other network measures follow analogously.

Following the earlier notation, the econometric models involve measures of degree centrality, D_{it}, as dependent variable and location specific covariates at the place of residence denoted by L_r. Hence, we specify the benchmark model as

$$D_{ir,t} = \alpha + L'_{r,t}\beta + X'_{ir,t}\gamma + \lambda_t + \lambda^l_r + \epsilon_{ir,t}, \tag{4.11}$$

[8] The main motivation behind this approach is usually the possibility of oversampling rare alternatives, which can improve the accuracy of the econometric analysis but also reduce survey costs. However, in our case we undersample those dyads with $g_{ij,t} = 0$ in order to enhance computational efficiency. One disadvantage is that most specification tests for non-linear models are not computable with sample weights.

where $X_{ir,t}$ is a vector of individual characteristics (i.e. commuting distance, language, dummy for belonging to language minority, gender, and age), λ_t stands for month fixed effects, and λ_r^l denotes language region fixed effects. The location vector $L_{r,t}$ includes indicators for EUROSTAT's harmonised definition of functional urban areas which distinguish between the urban core, the hinterland and peripheral regions. Alternatively, we measure local density using the number of private mobile phone customers within 15 minutes travel time from the respective place. Unlike municipal population statistics this measure has the advantage that it is independent from administrative boundaries.

In a next step, we address the issue of individual sorting on unobservables across locations. If the most sociable individuals systematically sort into high-density places, equation (4.11) would yield upwardly biased estimates of the density externality. Compared to the pooled OLS specification, we add an individual fixed effect in order to disentangle the density externality and the sorting effect, i.e.

$$D_{ir,t} = \mu_i + L'_{r,t}\beta + X'_{ir,t}\gamma + \lambda_t + \lambda_r^l + \epsilon_{ir,t}. \tag{4.12}$$

Note that this model identifies the effects on the basis of movers i.e. those who changed their place of residence between July 2015 and April 2016. These are about 147'000 individuals in the unfiltered data or 6% of the operator's private customers (see Table A.4). One concern in introducing fixed effects is that movers may differ systematically from the population. Like reported in other studies that adopt a similar identification strategy (e.g. D'Costa and Overman, 2014), movers in our data are on average younger than non-movers. Apart from age, Table A.5 shows that differences in both individual characteristics as well as phone usage behaviour and network properties are sufficiently small between both groups.

4.5 Results

The results section is structured as follows: We begin by discussing the main results for the network formation model. Our focus is on the question of whether distance is costly to social interactions (section 4.5.1). In a second step, we analyse differences in network size across regions, to test the hypothesis that cities promote social interactions (section 4.5.2). We then proceed to investigate, whether population density affects the efficiency of networks. To draw conclusions regarding network efficiency, we analyse the perimeter of social networks (section 4.5.3), examine regional differences in matching quality (section 4.5.4), and finally aim to gain insights regarding clustering (section 4.5.5).

4.5.1 The Role of Distance and Other Determinants in Tie Formation

It is instructive to begin by looking at plain descriptives. Figure 4.4 plots the share of ties along the share of potential contacts by radius. Considering that almost 50 percent of bilateral ties are formed within a 5 km perimeter that covers on average less than 1 percent of the population, this illustrates the rapid decline of social interactions across space.

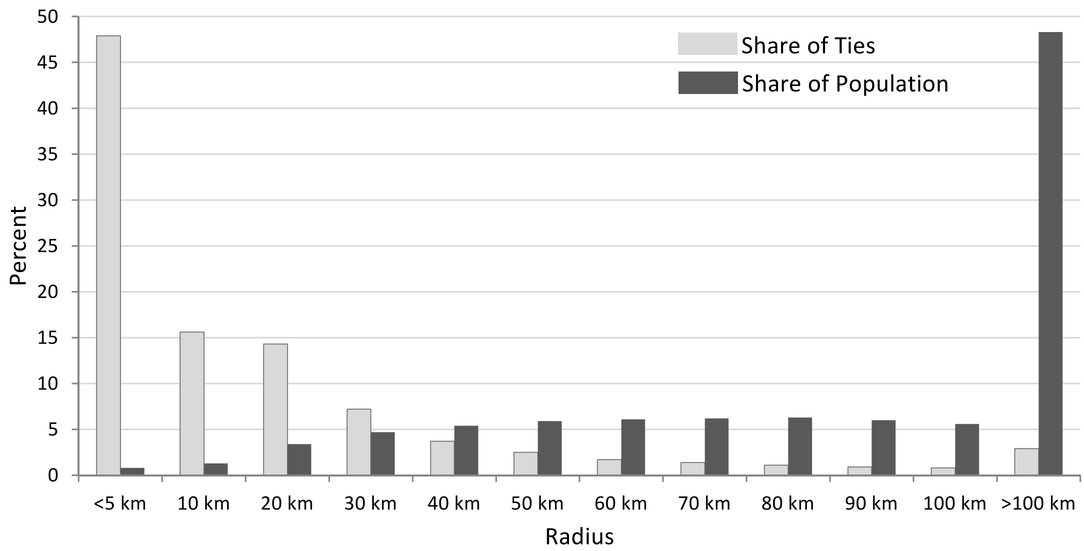


Figure 4.4: Share of Social Ties and Population by Radius

Of course, this approach does not account for biases due to spatial sorting of similar types. We therefore proceed to the network formation models, outlined in the previous section. Table 4.2 presents the result for the linear probability model. All coefficients were multiplied by 10'000 and therefore can be interpreted as basis points. This means that a coefficient equalling one translates to a marginal increase in $P(g_{ij,t} = 1)$ of a hundredth percentage point. The first two columns display pooled OLS estimations, the middle columns report pair fixed effects models, and the last two columns show lagged dependent variable specifications. In all models estimated, the travel time between two agents enters negatively, implying that *distance* is indeed costly when forming and maintaining a link. Columns (2), (4) and (6) reveal that tie formation is actually a convex function in distance; the log of travel time enters strongly negative, while the squared term is positive. Their relative magnitudes suggest that the negative effect of distance completely fades at approximately 90 minutes driving distance.

In addition to being neighbours, *working in the same area* also increases the likelihood that two persons form a link. The coefficient for the dummy variable “Same Workplace”, which equals one if agents i and j predominantly use antennas within the same 5 km radius during business hours, ranges between 0.07 and 0.1. Hence, working in close proximity increases the probability of forming a tie by about 0.1 basis point, which is roughly ten times the estimated effect of speaking the same principal language. Taken together, distance in terms of both residence and workplace are costly to social interactions.

In order to analyse preferences for triadic closure or *clustering*, we discretise the number of common friends, such that we obtain two dummy variables: one indicating that agents i and j share at least one common social contact, and the other indicating that they share at least two common contacts. The coefficients for both “Common Contact” variables are highly significant. Column (2) shows that the probability of forming a link with another person increases by up to

Table 4.2: LPMs of Network Formation, Monthly Data for June 2015–May 2016.

	Pooled OLS		Panel FE		Lagged Dependent Var.	
	(1)	(2)	(3)	(4)	(5)	(6)
Ln(Travel Time$_{ij,t}$)	-0.112***	-0.942***	-0.024***	-0.094***	-0.053***	-0.479***
	(0.000)	(0.053)	(0.000)	(0.019)	(0.000)	(0.024)
Ln(Travel Time$_{ij,t}$)^2		0.104***		0.010***		0.053***
		(0.006)		(0.002)		(0.003)
Same Workplace$_{ij,t}$		0.166***		0.071***		0.100***
		(0.030)		(0.002)		(0.014)
Same Language$_{ij,t}$		0.017***				0.009***
		(0.001)				(0.001)
>0 Common Contacts$_{ij,t-1}$		213.822***		11.840***		100.943***
		(10.101)		(0.928)		(4.866)
>1 Common Contacts$_{ij,t-1}$		2257.176***		145.633***		1024.429***
		(331.296)		(35.656)		(159.448)
$g_{ij,t-1}$					5231.433***	4973.641***
					(2.929)	(34.689)
Const.	0.545***	2.079***	0.135***	0.224***	0.256***	1.060***
	(0.001)	(0.114)	(0.002)	(0.038)	(0.000)	(0.052)
R^2	0.001	0.054	0.001	0.001	0.275	0.288
Further Controls	No	Yes	No	No	No	Yes
Pair FE	No	No	Yes	Yes	No	No
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Groups	–	–	2,584,869	2,582,702	–	–
Observations	30,996,082	27,238,673	30,996,082	27,238,673	28,411,817	27,238,673

Notes: The *sample* covers movers who used their phone every month at least once. All *coefficients* of the linear probability models are multiplied by 10000, and therefore can be interpreted as basis points. *Further controls* include the degree for both agents (log), dummies for same gender and same age, as well as the absolute age difference between agents i and j. Standard errors in parentheses. + $p<0.10$, * $p<0.05$, ** $p<0.01$ *** $p<0.001$.

22 percentage points, if one shares at least two common contacts. As one would expect, the estimates are considerably smaller in column (4), which controls for matching quality by employing dyad-specific fixed effects. Nonetheless, the additional link-surplus of 1.5 percentage points due to triangular relations – as obtained in the most conservative specification – is quantitatively substantial. Agents clearly value triadic relations, which explains the evidently non-random clustering in this network, as discussed in section 4.3.1.

Overall *matching quality* between two agents is not observable, but the regressions in column (2) and column (6) account for socio-demographic (dis)similarities that are incorporated in the matching concept, namely dummies for same language, same gender and same age, as well as the absolute age difference between customers i and j. If we abstract from potential omitted variable bias and assume that $m(\cdot)$ is a linear and additive function, the interpretation of the estimated coefficients in terms of matching is as follows: By definition $\frac{\partial E[g_{ij}|m(\cdot)]}{\partial m(\cdot)} > 0$, therefore $sign(\hat{\rho_q}) = sign(\delta_q)$ holds. Accordingly, a positive (negative) sign not only implies an increase in the probability that two agents socially interact, but also a positive (negative) relation in terms of matching quality. Our results unambiguously point toward homophily, which is the well documented tendency of individuals to bond with similar others (e.g. McPherson, Smith-Lovin and Cook, 2001; Currarini, Jackson and Pin, 2009). For instance, individuals who share the same principal language are on average more likely to form a tie than individuals with different language preferences. The same holds true regarding age and gender (results not shown).

Table 4.3: Logit Models of Network Formation, Monthly Data for June 2015–May 2016.

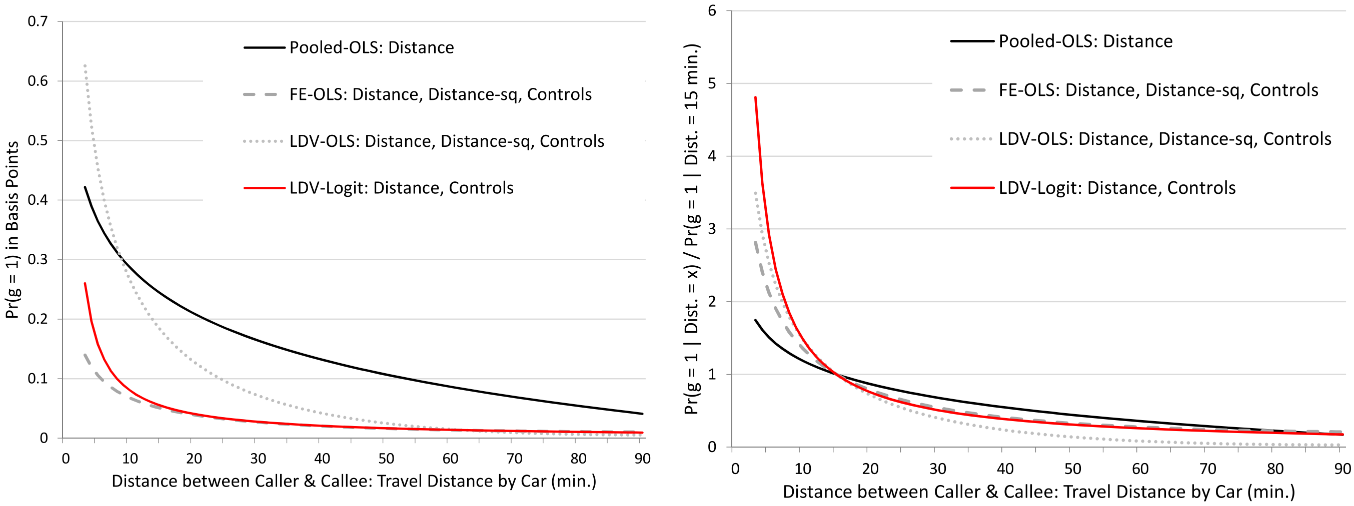
	Pooled Logit		Lagged Dependent Var.	
	(1)	(2)	(3)	(4)
Ln(Travel Time$_{ij,t}$)	-1.410***	-0.877***	-1.131***	-0.976***
	(0.002)	(0.049)	(0.001)	(0.005)
Same Workplace$_{ij,t}$		0.893***		1.085***
		(0.161)		(0.013)
Same Language$_{ij,t}$		1.813***		1.685***
		(0.057)		(0.005)
>0 Common Contacts$_{ij,t-1}$		7.363***		4.786***
		(0.122)		(0.070)
>1 Common Contacts$_{ij,t-1}$		2.323***		-0.018
		(0.352)		(0.071)
$g_{ij,t-1}$			12.218***	9.868***
			(0.003)	(0.029)
Const.	-7.357***	-12.951***	-8.958***	-11.170***
	(0.010)	(0.249)	(0.007)	(0.026)
Pseudo R^2	0.138	0.376	0.492	0.527
Further Controls	No	Yes	No	Yes
Pair FE	No	No	No	No
Month FE	Yes	Yes	Yes	Yes
Observations	30,996,082	27,238,673	28,411,817	28,411,817

Notes: The *sample* covers movers who used their phone every month at least once. *Further controls* include the degree of both agents (log), dummies for same gender and same age, as well as the absolute age difference between agents i and j. Standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

The OLS results suggest that spatial proximity, the presence of common friends, and demographic similarity increase the likelihood that two individuals interact. We also estimate *Logit models* to accommodate for the binary dependent variable and check the robustness of these results. Since the incidental parameter problem can induce severe bias in the Logit fixed effects estimates (e.g Lancaster, 2000), we only show results for the pooled Logit model and the lagged dependent variable model. Moreover, the squared distance term is excluded due to convergence issues, which should be a minor problem given the Logit estimator's inherent non-linearity. The results in Table 4.3 are qualitatively almost identical to the OLS results in Table 4.2, except for one of the common friends dummies, which turns out insignificant in column (4). Hence, in terms of qualitative interpretation the main results are very robust with respect to modelling choice.

We now inspect the functional relation between distance and tie formation in more detail. Figure 4.5a displays the predicted probability for $g_{ij} = 1$ based on various specifications. Figure 4.5b plots the relative probability for $g_{ij} = 1$ compared to the base probability at a distance of 15 minutes travel time. Although the models differ somewhat regarding the level prediction, they consistently reveal a convexly decreasing relation between link formation and distance. Overall, the graphs illustrate that the effect of distance on social interactions is highly localised; the probability of forming a link is about twice as large for neighbours than for people living 10 minutes apart. This probability continues to fall quickly up to a distance of 30 minutes, beyond which the negative effect of travel time flattens out.

Summarising this comprehensive evidence, we have been able to demonstrate that distance is highly detrimental to social interactions. If distance between two individuals did not impose



(a) Level

(b) Ratio, Base Distance = 15 min.

Figure 4.5: Probability to Form a Tie: Prediction Based on OLS and Logit Models
Notes: Same Workplace=0, Common Contacts=0, Degree=mean, Same Gender=1, Same Age=1, Age Diff=0, $g_{ij,t-1}$=0, FE=0.

costs on their social exchange, it would be difficult to argue that regional differences in population density should impact the topography of social networks. In such a – with respect to distance – frictionless world, cities and rural villages would offer an identical environment for social interactions as all people could choose from the same pool of potential contacts without there being any costs due to remoteness.

In what follows, we examine whether distance costs indeed lead to significant differences in the topography of social networks across urban and rural areas. First, we examine the consequences regarding network size, and then we turn our attention to network efficiency.

4.5.2 Cities and Network Size

A number of urban economic theories argue that cities are favourable to social interactions and support larger networks. As discussed in section 4.2, the underlying idea is that people living in densely populated areas encounter more potential contacts, and accordingly establish a larger number of valuable social ties. So far, we have presented evidence suggesting that distance is indeed costly to forming and maintaining a tie, which is a necessary condition for the hypothesis of larger networks in cities.

In order to directly test the hypothesis, we estimate a series of pooled OLS models, which are reported in Table 4.4. We use two sets of key explanatory variables, including the trichotomous classification for urbanisation by EUROSTAT (i.e. urban core, hinterland, periphery) as well as a continuous measure for population density. The latter is defined as the log of the population living within a 15-minute radius of an individual's postcode area. Network size is measured on a monthly basis as degree centrality, i.e. the number of unique contacts an individual calls during one month.

Table 4.4: Regional Differences in Network Size, Monthly Data for June 2015–May 2016.

	Pooled OLS					
	(1)	(2)	(3)	(4)	(5)	(6)
Hinterland (vs. Cities)	-0.024***			-0.025***		
	(0.001)			(0.001)		
Periphery (vs. Cities)	-0.011***			-0.017***		
	(0.001)			(0.001)		
Ln(Pop. Density)		-0.012***	-0.223***		-0.008***	-0.222***
		(0.000)	(0.002)		(0.000)	(0.002)
Ln(Pop. Density)^2			0.012***			0.012***
			(0.000)			(0.000)
R^2	0.011	0.012	0.013	0.067	0.067	0.068
Further Controls	No	No	No	Yes	Yes	Yes
Language Region FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	10,117,645	10,117,522	10,117,522	9,353,794	9,353,679	9,353,679

Notes: The *sample* covers customers who used their phone every month at least once. *Further controls* include commuting distance, language, dummy for belonging to language minority, gender, and age. Standard errors in parentheses. + $p<0.10$, * $p<0.05$, ** $p<0.01$ *** $p<0.001$.

Columns (1) and (4) contain the results for the discretised measure of urbanisation, the former excluding and the latter accounting for individual controls in the regression. Agents who live in the hinterland or periphery have on average a smaller network than city residents. The correlations are statistically highly significant, with an average difference of -1.1 to -1.7 percent when comparing the urban core to the periphery, and -2.4 to -2.5 percent when comparing the urban core to the hinterland.

The continuous population density measure in columns (2) and (5) is negatively correlated with network size. This unexpected result is due to non-linearities, as the results in columns (1) and (4) already indicate; although the hinterland has a higher population density than peripheral municipalities, the hinterland coefficient is significantly smaller than the periphery coefficient. When a squared-term is included, the results indeed reveal a convex relation between population density and network size, with the marginal effect of population density turning positive around its mean value.

Overall, these findings lend support to the hypothesis that dense urban areas facilitate social interactions, backing earlier studies that report a positive correlation between the level of urbanisation, the volume of phone calls, and network size (e.g. Charlot and Duranton, 2004; Schläpfer et al., 2014). So far it is unclear, however, whether the effect has a causal interpretation or is driven by the sorting of high sociability types to urban centres.

In a next step, the regressions include individual fixed effects to back out any person specific characteristics and thereby eliminate the sorting channel. Consequently, inference is now based on customers who changed their billing address during the 12 months period covered. Columns (1) to (3) of Table 4.5 display results for the baseline fixed effects regression, while columns (4) to (6) show a robustness check based on people who changed their residence by at least 30 minutes driving time. The results stand in stark contrast to the plain OLS regressions and clearly reject the hypothesis that cities have a causal impact on network size. All coefficients related to

Table 4.5: Regional Differences in Network Size, Monthly Data for June 2015–May 2016.

	FE: Full Sample			FE: Moving Distance > 30min.		
	(1)	(2)	(3)	(4)	(5)	(6)
Hinterland (vs. Cities)	0.000			-0.006		
	(0.003)			(0.006)		
Periphery (vs. Cities)	0.000			-0.001		
	(0.004)			(0.007)		
Pop. Density		-0.002	-0.001		-0.002	-0.006
		(0.001)	(0.012)		(0.002)	(0.017)
Pop. Density^2			-0.000			0.000
			(0.001)			(0.001)
R^2	0.011	0.011	0.011	0.011	0.011	0.011
Further Controls	Yes	Yes	Yes	Yes	Yes	Yes
Language Region FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Groups	60,514	60,514	60,514	16,874	16,874	16,874
Observations	669,825	669,825	669,825	185,676	185,663	185,663

Notes: The *sample* covers movers who used their phone every month at least once. *Further controls* include commuting distance and a dummy for belonging to language minority. Standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

regional differences in population density are practically zero and statistically insignificant.

Figure B.1 in the appendix plots the degree of movers over time. It shows that agents expand their social network in the three months prior to moving, and then revert to their initial level within two months. To test the robustness of our results with respect to this dynamic, we re-estimate the fixed effects models for movers who changed their residence by at least 30 minutes driving time and successively exclude periods around the moving month. Table B.1 in the appendix shows that only 2 out of 20 coefficients turn out statistically significant at the 10 percent level. Hence, these additional results do not alter the conclusion from the benchmark analysis in Table 4.5.[9]

It seems, then, that the correlation between population density / urbanisation and network size is fully driven by the sorting of above-average sociable people to the urban core and cannot be attributed to the positive externalities of people living close together. A variance decomposition, which computes the contributions of individual fixed effects, local fixed effects, and time specific factors to the total variance of $D_{i,t}$, also supports the conclusion that regional differences play a small role in explaining differences in network size. Individual components contribute 73.0 percent to the overall variance of degree centrality, while local factors only explain 2.3 percent.

[9] One further concern may be that urban dwellers use messenger apps more frequently than people in rural areas, which could lead to a downward bias in the population density / city dummy estimates. Although we can not rebut such concerns with absolute certainty, they seem unsubstantiated for two reasons. *First*, messenger apps and mobile phone calls are most likely *complements* not *substitutes*. We decompose messenger usage along gender and language region, based on a survey conducted by *comparis.ch* in 2014. It shows that messenger apps are more often used among men than women and are more widespread in French-speaking than German-speaking regions. The same ranking unfolds for network size. If anything, this indicates that the two media are complements not substitutes. Additionally, a paper on workplace communication by Charlot and Duranton (2006) shows that telephone usage is complementary to all other modes of communication studied, including face-to-face communication, letter correspondence, email traffic, and internet usage. *Second*, we conduct a series of robustness checks, in which we control for an individual's communication preference based on his monthly text message–call volume ratio. These robustness checks do not alter the results.

The remaining variation can be attributed to time specific factors (0.3%) and to the residual (24.4%), i.e. individual and time variant components.

This analysis provides evidence that the correlation between population density and network size is primarily driven by the sorting of highly sociable people to urban centres. Sociability may thereby refer to the mental capability of maintaining social ties, as suggested by the social brain hypothesis (e.g. Dunbar, 1998), and/or to personality traits, as advocated by Asendorpf and Wilpers (1998). This raises the question of why people with an above-average sociable predisposition move to cities. One evident explanation could be that cities provide a favourable environment for social interactions, which does not manifest itself in terms of network size but rather with respect to network efficiency. If this were the case, individuals with a preference for and capability of maintaining large networks would disproportionally benefit from moving to cities, which could explain the sorting pattern uncovered in the above analysis.

4.5.3 Cities and the Perimeter of Social Networks

We begin the discussion of network efficiency by examining variations in network perimeters across regions. Everything else being equal, an agent is better off the less distant his social contacts live, simply because he will incur lower travel costs. Since people residing in cities have a larger pool of potential contacts within close proximity, one would expect them to recruit their social contacts within a narrower perimeter to minimise travel costs.

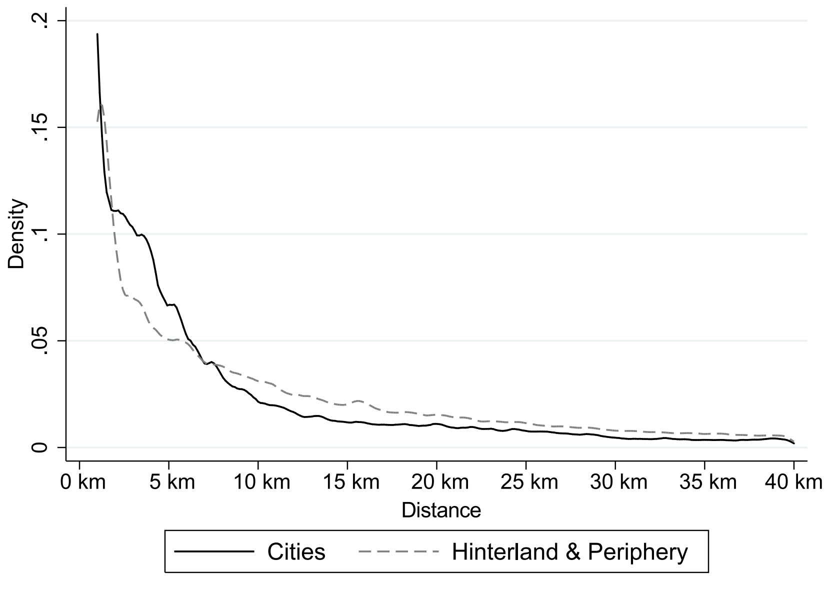


Figure 4.6: City versus Hinterland / Periphery – Density Plot for Social Ties by Radius.
Notes: The density plot starts at 1 km; links spanning shorter distances (mostly links within the same postcode) were assigned a value of 1 km.

We analyse the impact of population density on the perimeter of an individual's network in three steps. First, we discuss descriptive evidence based on a density plot for social ties by

Table 4.6: Regional Differences in the Perimeter of Social Networks, Monthly Data for June 2015–May 2016.

a. Network Formation	Pooled OLS		Panel FE	
Cities & Distance	(1)	(2)	(3)	(4)
Ln(Distance$_{ij,t}$)	-0.068***	-0.069***	-0.016***	-0.016***
	(0.003)	(0.003)	(0.001)	(0.001)
Ln(Distance$_{ij,t}$) × City$_{i,t}$	-0.001***		-0.001**	
	(0.000)		(0.000)	
Ln(Distance$_{ij,t}$) × Pop. Density$_{i,t}$		-0.001***		-0.001***
		(0.000)		(0.000)
R^2	0.054	0.054	0.001	0.001
Further Controls	Yes	Yes	Yes	Yes
Pair FE	No	No	Yes	Yes
Month FE	Yes	Yes	Yes	Yes
Groups	–	–	2,582,702	2,582,702
Observations	27,238,673	27,238,673	27,238,673	27,238,673
b. Network Topography	Pooled OLS		Panel FE	
Cities & Within-Degree (15 min.)	(1)	(2)	(3)	(4)
Hinterland (vs. Cities)	-0.111***		-0.123***	
	(0.001)		(0.010)	
Periphery (vs. Cities)	-0.208***		-0.231***	
	(0.001)		(0.012)	
Population Density		0.086***		0.143***
		(0.000)		(0.004)
R^2	0.049	0.056	0.010	0.018
Further Controls	Yes	Yes	Yes	Yes
Individual FE	No	No	Yes	Yes
Language Region FE	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes
Groups	–	–	60,514	60,514
Observations	9,353,794	9,353679	669,825	669,812

Notes: The *sample* covers movers who used their phone every month at least once. *a. Controls in network formation models:* Dummies for same workplace, same language, common contacts, degree of both agents (pooled OLS), same gender (pooled OLS), same age (pooled OLS), and the absolute age difference between agents i and j (pooled OLS). *b. Controls in network topography models:* Commuting distance, language minority dummy, gender (pooled OLS) and age (pooled OLS). Standard errors in parentheses. + $p<0.10$, * $p<0.05$, ** $p<0.01$ *** $p<0.001$.

radius and location type (i.e. cities versus hinterland/periphery). Second, we use the network formation model to test whether urban dwellers value distance differently than people living in less densely populated areas. Third, we calculate the within-degree, which measures network size within a radius of 15 minutes around an agent's residence, to analyse whether it varies systematically with population density.

Figure 4.6 plots the density of social ties by radius and location type. In comparison to individuals living in the hinterland or periphery, urban dwellers evidently have a larger mass of social contacts within a 7 km radius, and fewer contacts beyond. This supports the hypothesis that living in a city can lower the costs incurred from social interactions with distant contacts.

In order to examine this claim further we use the network formation model and interact the log of distance with either population density or the city dummy. The top panel of Table 4.6 reports the output of the augmented network formation model, with columns (1) and (2) displaying the OLS results and columns (3) and (4) showing the pair fixed effect estimates. All specifications suggest that urban dwellers incorporate distance costs more strongly in their valuation than people living in peripheral areas. The interaction terms yield statistically significant negative effects, but are quantitatively relatively small.

Finally, we resort to our network topography model using the within-degree, DW_i^r, as dependent variable. The bottom panel of Table 4.6 reports the outputs of this approach, with columns (1) and (2) displaying the OLS results and columns (3) and (4) showing the individual fixed effect estimates that account for the sorting of highly sociable individuals to urban areas. As hypothesised, the within-degree is largest in urban areas and positively correlated with population density. This holds true for both the plain OLS estimates, as well as the individual fixed effects results. According to our causal estimates from the individual fixed effects specification, urban dwellers have on average a 10 percent larger within-degree than individuals residing in the hinterland, and a 23 percent larger within-degree than people living in peripheral areas. The results also show that doubling population density leads, on average, to a 6.8 percent higher within-degree.[10] While population density is hardly relevant for overall network size, it has considerable explanatory power regarding the number of close-range contacts. The variance decomposition also reveals that regional factors explain more than twice as much of the within-degree variance (4.9%) than the variance in network size (2.3%).

Densely populated areas evidently shrink the perimeter of an individual's social network, in the sense that a larger fraction of her social contacts are likely to live in close proximity. Considering that distant social contacts are costly, this consequently suggests that urban dwellers bear fewer costs from social interactions than people living in sparsely populated areas. This could – at least partly – explain why sociable people sort into cities, as they disproportionally benefit from this channel and therefore have a higher willingness to pay for housing in cities than less sociable types. This result may also be interpreted as better matching in cities, because geographical distance is essentially one dimension of matching quality. We further explore matching quality across regions in the following section.

4.5.4 Cities and Matching

Since matching quality cannot be directly observed, we propose two indirect tests for the hypothesis that matching quality improves with population density. In one test we resort to the network formation model, while the second test is based on the network topography approach.

We begin with the *network formation model*, or more specifically with the fixed effect specification given in equation (4.10b.): The pair fixed effect absorbs any dyad-specific constant factors that either raise or lower the surplus of interaction for the involved agents. Hence, it primarily captures matching quality, $m(\cdot)$, which governs the value obtained from forming a link with another person. If agents living in cities indeed benefit from better matching quality, we would expect that fixed effects associated with their actually formed links are higher than the equivalent fixed effects calculated for agents living in rural areas. To test this claim, we first

[10] As for the degree, we re-estimate the fixed effects models and successively exclude periods around the moving month. Table B.2 in the appendix shows that this does not affect the results.

Table 4.7: Regional Differences in the Matching Quality

a. Network Formation	Full Sample		Moving Distance > 30min.	
Cities and Matching (Predicted FE)	(1)	(2)	(3)	(4)
$\text{Hinterland}_{i,t}$	-55.595***		-59.265***	
	(5.928)		(11.127)	
$\text{Periphery}_{i,t}$	-145.315***		-117.816***	
	(6.451)		(11.832)	
Pop. $\text{Density}_{i,t}$		34.954***		17.834***
		(1.856)		(2.815)
Constant	2492.994***	2085.201***	2466.674***	2232.319***
	(492.036)	(115.281)	(250.231)	(84.219)
R^2	0.001	0.001	0.001	0.001
Observations	11,616,147	11,692,984	3,089,595	3,116,907

b. Network Topography	Full Sample		Moving Distance > 30min.	
Cities and Matching (Social Adaption)	(1)	(2)	(3)	(4)
City_{post}	0.327***		0.090	
	(0.046)		(0.056)	
City_{pre}	-0.449***		-0.275***	
	(0.033)		(0.044)	
Pop. Density_{post}		0.227***		0.076***
		(0.011)		(0.013)
Pop. Density_{pre}		-0.326***		-0.138***
		(0.014)		(0.020)
Constant	1.009***	1.801***	0.685***	1.256***
	(0.097)	(0.176)	(0.037)	(0.194)
R^2	0.047	0.078	0.259	0.263
Further Controls	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes
Language Region FE	Yes	Yes	Yes	Yes
Observations	28,871	28,871	7,887	7,801

Notes: *Dependent Variable in Panel a.:* Predicted dyad specific fixed effect from network formation model outlined in equation (4.10b). *Dependent Variable in Panel b.:* The number of *post-move* contacts at the *post-move* place of residence over the number of *post-move* contacts at the *pre-move* place of residence. *Controls in Panel b.:* Number of contacts at new address prior to moving, commuting distance, dummy for belonging to language minority, gender and age . Standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

estimate equation (4.10b.), and then regress the predicted pair fixed effects for the subsample of active links (i.e. $g_{ij} = 1$) on population density at agent i's place of residence. Because we focus on movers to back out any distance-related effects, the estimates yield the impact of population density weighted by duration of stay.[11] We obtain strong positive and significant effects for population density in column (2), and negative effects for residents of peripheral municipalities in column (1). Restricting the sample to customers with a minimum driving distance of 30 minutes between their old and new addresses does not affect the results. This backs the claim that densely populated areas lead to favourable matching outcomes.

In the next step, we reassess the hypothesis by returning to the *network topography approach.* If people change their residence, we would expect them to keep up with some of their previous contacts and replace others with individuals living in their new neighbourhood. Since distance makes social interactions costly, only highly valuable contacts at the old place of residence

[11]As a robustness check, we also restrict the sample to movers who change their residence but stay within the same class of municipalities, i.e. moving from city to city or from hinterland to hinterland. As Table B.4 in the appendix reveals, this does not alter the results.

are worthwhile to maintain. Furthermore, if one encounters very good matches at the new place of residence, the replacement of pre-existing ties with new contacts should advance more quickly. We therefore examine whether this social adjustment process systematically varies with population density at the pre- and post-move residence. Specifically, we estimate

$$\frac{DW_{i,post}^{r_{post}}}{DW_{i,post}^{r_{pre}}} = \alpha + \beta_{r_{post}} \cdot L_i^{r_{post}} + \beta_{r_{pre}} \cdot L_i^{r_{pre}} + X_i'\gamma + \varrho DW_{i,pre}^{r_{post}} + \epsilon_i, \tag{4.13}$$

where the ratio $DW_{i,post}^{r_{post}}/DW_{i,post}^{r_{pre}}$ reflects the number of *post-move* contacts at the *post-move* place of residence over the number of *post-move* contacts at the *pre-move* place of residence. The main explanatory variables are population density and the trichotomous classification for urbanisation at mover i's new address ($L_i^{r_{post}}$) and old address ($L_i^{r_{pre}}$), complemented with a measure for the number of pre-move contacts at the new address ($DW_{i,pre}^{r_{post}}$), and individual level characteristics X_i.[12] The results reported in the bottom panel of Table 4.7 are based on address changes between October 2015 and January 2016, a pre-move window covering June 2015 to August 2015, and a post-move window covering March 2016 to May 2016. As hypothesised, the fastest social adjustment process is observed for people who move from the periphery to the city, while movers who lived in urban areas before changing their address keep comparatively large shares of their pre-move contacts. Since maintaining spatially distant contacts is costly, this suggests that contacts formed in cities generate on average a higher surplus and are therefore more likely to be maintained. Hence, this test further supports the hypothesis that densely populated areas improve matching quality.

So far, our results suggest that high population density in cities does not lead to *larger* social networks, but rather improves their efficiency in terms of narrower perimeters and matching quality. We are not aware of any paper providing evidence on regional differences in social matching quality, which is a key factor underlying the main agglomeration forces as formally discussed in Duranton and Puga (2004).

4.5.5 Cities and Clustering

The final network property that we examine is clustering. Agents face a trade-off in terms of efficient information exchange (i.e. low clustering) and benefits related to reciprocity (i.e. high clustering). The optimal balance may vary regionally due to factors that alter this trade-off. Additionally, one would expect that more populous neighbourhoods display lower average clustering, simply because randomly established links are less likely to form triadic structures when the pool of potential contacts grows larger. To test the first claim, we resort to the network formation model. Even if there is no evidence that urban dwellers value triadic relations differently than people living in rural communities, the mechanical relation between population density and clustering may lead to measurable regional differences. If this is the case, the

[12] Instead of controlling for the pre-move contacts at the new address, we also re-estimate the model for a subsample of customers that move to a location where they have no prior contacts, i.e. $DW_{i,pre}^{r_{post}} = 0$. This does not alter the conclusion, as the results in Table B.4 (Panel b.) in the appendix show.

Table 4.8: Regional Differences in the Transitivity of Social Networks, Monthly Data for June 2015–May 2016.

a. Network Formation			Panel FE	
Cities & Common Friends			(3)	(4)
>0 Common Contacts$_{ij,t-1}$			17.337***	16.477***
			(1.268)	(1.058)
>0 Common Contacts$_{ij,t-1}$ $\times$ City$_{i,t}$			-3.681^{+}	
			(2.009)	
>0 Common Contacts$_{ij,t-1}$ $\times$ Pop. Density$_{i,t}$				-1.745^{+}
				(0.957)
R^2			0.001	0.001
Further Controls			Yes	Yes
Pair FE			Yes	Yes
Month FE			Yes	Yes
Groups			2,582,702	2,582,702
Observations			27,238,673	27,238,138
b. Network Topography	Pooled OLS		Panel FE	
Cities & Clustering	(1)	(2)	(3)	(4)
Hinterland (vs. Cities)	0.010***		0.002*	
	(0.001)		(0.001)	
Periphery (vs. Cities)	0.014***		0.002**	
	(0.001)		(0.001)	
Population Density		-0.004***		-0.001**
		(0.001)		(0.000)
R^2	0.022	0.022	0.001	0.001
Further Controls	Yes	Yes	Yes	Yes
Individual FE	No	No	Yes	Yes
Language Region FE	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes
Groups	–	–	60,507	60,507
Observations	9,252,183	9,252,183	664,343	664,330

Notes: The *sample* covers movers who used their phone every month at least once. *a. Controls in network formation models:* Dummies for same workplace, same language, common contacts, degree of both agents (pooled OLS), same gender (pooled OLS), same age (pooled OLS), and the absolute age difference between agents i and j (pooled OLS). *b. Controls in network topography models:* Commuting distance, dummy for belonging to language minority, gender (pooled OLS) and age (pooled OLS). Standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

network topography approach should be able to uncover them.

We begin with the network formation model and interact the dummy for common contacts with either population density or the city dummy. In order to back out spurious clustering due to the grouping of similar types, we focus on the pair fixed effects specification. The top panel of Table 4.8 reports the results for these regressions. In both specifications, the interaction terms are negative and statistically significant at the 10 percent level. Hence, this analysis suggests that sharing a common link is valued less by urban dwellers than by residents of peripheral areas. Magnitude wise the impact is fairly substantial, as it amounts to approximately 20 percent of the effect attributed to the common contact dummy. While sharing a common contact increases the probability of forming and maintaining a link by 17.3 basis points, the effect is only 13.7 basis points among city residents.

Given the results of the network formation analysis, we expect lower clustering in cities than in peripheral areas. First, city residents seem to value triadic relations less than people living in peripheral areas. Second, the larger pool of potential contacts lowers the likelihood of triadic relations, at least if there is some randomness in the link formation process. The bottom panel of Table 4.8 displays the results of the network topography analysis with clustering as the dependent variable. Both the pooled OLS regressions in columns (1) and (2), as well as the fixed effects specifications in columns (3) and (4) suggest that cities attenuate network clustering. The effect ranges between -0.010 and -0.014 in the pooled OLS regressions, which is roughly 11 to 15 percent of the sample mean. The difference between city and hinterland / periphery drops by 80 percent in the fixed effects specifications, but remains significant at the 5 percent level or higher.[13]

Despite the evidence that population density has no impact on the number of social interactions, cities may facilitate the diffusion of information due to below-average clustering. This can have important consequences for local labour markets, as discussed in Sato and Zenou (2015), for example. In conjunction with the findings on network size, matching quality and distance costs, this suggests that cities may encourage not a larger number but rather more valuable social interactions.

4.6 Conclusion

The results of this study suggest that that cities provide a superior environment for social interactions, which is fundamentally important to the mechanics of classic agglomeration forces. Contrary to many theoretical models, the advantages of densely populated areas do not translate into larger social networks but rather into improvements in terms of matching quality, smaller distance costs, and a favourable structure for information diffusion (i.e. lower clustering).

Evidently, modern communication technologies do not render cities obsolete. Our analysis has illustrated that they remain important as catalyst of valuable social exchange and, consequently, as potential engines of growth. From a policy perspective, this result provides micro-level evidence for the positive externalities of densely populated areas, which should be taken into account, for example, in the design of zoning policies, or the pricing of mobility.

There are many potential extensions of the work described in this paper. First and foremost, a quantification of the effects in monetary terms would be insightful, and – in our opinion – would be the first attempt to plausibly identify the causal link between density, social interactions, and a measure of productivity / output. Second, we focused exclusively on private social interactions, thus it would be fruitful to examine whether the same conclusions apply to networks from business communication. Third, we barely scratched the surface of the information available in the mobility data recorded from transmitting antennas. Such data would allow, for instance, to thoroughly test the influential claim by social scientist Robert Putnam (2000) that commuting causes an erosion of social capital.

[13] Successively excluding periods around the moving month, as done in Table B.3, yields occasionally insignificant results for the Hinterland dummy, but overall the same pattern as in the benchmark model emerges.

A. Appendix: Data

Descriptive Statistics – Municipalities and Postcode Areas

Table A.1: Main Descriptives for Municipalities and Postcode Areas

	Mean	SD	Min	Max
	Municipal Level (N=2322)			
Area in km^2	17.412	31.434	0.327	438.562
Population (from 2010 Census)	2396	3397.175	12	384786
Market Share of Swisscom	0.577	0.096	0.090	0.997
Degree of Urbanization				
Core	0.035	–	0	1
Periphery	0.336	–	0	1
Hinterland	0.629	–	0	1
Main Language				
German	0.628	–	0	1
French	0.295	–	0	1
Italian	0.065	–	0	1
Rhaeto-Romanic	0.012	–	0	1
Distance: Municipality i to j (km)	107.611	58.955	0.581	348.644
Travel Time: Municipality i to j (min.)	134.004	66.897	0.692	433.696
	Postcode Level (N=3201)			
Area in km^2	12.927	19.215	0.014	242.904
# Customers within 15 min. Radius	14683	16818.31	50	107549
Distance: Postcode i to j (km)	111.931	59.501	0.336	353.852
Travel Time: Postcode i to j (min.)	142.804	69.033	0.283	453.508

Sources: Municipal and postcode areas from Swisstopo; municipal population, language shares, and degree of urbanisation from Federal Statistical Office; car travel times from *search.ch*; number of private mobile phone customers from *Swisscom*. Data from postcodes and municipalities with less than 50 customers were deleted due to privacy concerns.

Phone Usage Statstics

Table A.2: Call Duration (in Mio. Minutes) between June 2015 to May 2016

	Phone Activity (in Mio.)					Call Duration (in Mio. Minutes)			
	MP-Calls	SMS	Landline	**Total**	*Filtered*	MP-Calls	Landline	**Total**	*Filtered*
Jun. 2015	166.3	90.9	64.3	**321.6**	*66.0*	351.2	296.2	**647.4**	*222.4*
Jul. 2015	157.3	91.9	57.8	**307.0**	*62.0*	324.8	271.1	**595.9**	*202.2*
Aug. 2015	153.6	89.0	59.7	**302.3**	*60.3*	337.0	283.6	**620.6**	*211.3*
Sep. 2015	153.8	85.2	61.9	**300.9**	*61.6*	343.0	294.2	**637.2**	*216.9*
Oct. 2015	133.6	76.3	59.9	**269.8**	*53.7*	307.5	284.8	**592.3**	*192.6*
Nov. 2015	138.1	77.7	62.1	**277.9**	*56.5*	333.1	298.5	**631.6**	*208.7*
Dec. 2015	154.1	79.1	61.6	**294.8**	*62.0*	347.4	298.1	**645.5**	*218.5*
Jan. 2016	155.7	78.5	62.0	**296.2**	*61.0*	376.0	312.4	**688.4**	*235.5*
Feb. 2016	167.6	77.5	60.6	**305.7**	*66.3*	393.3	299.6	**692.9**	*246.7*
Mar. 2016	163.3	74.9	58.6	**296.8**	*65.4*	378.1	286.8	**664.9**	*240.3*
Apr. 2016	164.2	70.7	59.9	**294.8**	*65.7*	378.8	286.1	**664.9**	*241.1*
Mai 2016	161.1	68.6	55.9	**285.7**	*64.9*	353.5	264.6	**618.1**	*228.3*

Notes: These figures base on phone usage statistics of 2.4 million private mobile phones.

Descriptive Statistics – Individual Level

Table A.3: Share of Variance in Census Population Explained by Number of Customers

	All	Male	Female	German	French	Italian
Age All	0.987	0.984	0.988	0.992	0.990	0.893
Age 20	0.945	0.946	0.944	0.960	0.946	0.916
Age 30	0.953	0.955	0.951	0.953	0.973	0.765
Age 40	0.968	0.963	0.971	0.983	0.993	0.875
Age 50	0.985	0.982	0.984	0.993	0.988	0.914
Age 60	0.990	0.988	0.987	0.994	0.984	0.922

Notes: These figures base on customer information of active phones during June 2015 and the most recent census conducted by the Federal Statistical Office in 2010.

Table A.4: Number of Private Mobile Phone Customers with a Change in Residence

			DEGURBA Classification of Movers			
Month	All	Distance > 30min	City to Hint./Peri.	Hint./Peri. to City	Within Hint./Peri.	No Change
July	13880	4461	1468	1858	2864	7690
August	14212	4572	1431	1930	2923	7928
September	15636	4842	1584	2044	3160	8848
October	15673	4795	1572	2052	3229	8820
November	14820	4612	1537	1977	3070	8236
December	14053	4202	1396	1836	3229	7592
January	13292	4432	1194	2207	2708	7183
February	13705	4333	1275	2033	2807	7590
March	15171	4671	1501	2060	3181	8429
April	15838	4873	1529	2111	3234	8964

Notes: Movers are identified based on address changes in the customer database. Columns 3 to 6 document the moving pattern along the DEGURBA classification.

Table A.5: Comparing Non-movers to Movers, Main Descriptive Statistics

	Non-Movers			Movers			
	Mean	SD	N	Mean	SD	N	*Difference*
Phone Usage Statistics, June 2015 – May 2016 (pooled)							
Number of Calls	110.525	109.039	9 564 636	126.170	114.84	834 913	*-15.646*
Duration (Minutes)	250.840	293.322	9 564 636	302.285	316.835	834 913	*-51.445*
Network Characteristics, June 2015 – May 2016 (pooled)							
Degree Centrality	9.164	7.912	9 564 636	9.633	7.875	834 913	*-0.468*
Within-Degree	7.163	7.266	9 564 636	5.971	6.721	834 913	*1.192*
Clustering Coefficient	0.092	0.134	9 423 136	0.081	0.114	825 787	*0.011*
Sociodemographics - Private Mobile Phones							
Age	35.307	13.734	797 053	31.038	10.624	69 593	*4.269*
Female	0.522	–	797 053	0.527	–	69 593	*-0.005*
Language: German	0.680	–	797 053	0.703	–	69 593	*-0.023*
Language: French	0.271	–	797 053	0.251	–	69 593	*0.020*
Language: Italian	0.043	–	797 053	0.039	–	69 593	*0.004*
Language: English	0.006	–	797 053	0.007	–	69 593	*-0.001*

Notes: The table is based on the subsample of customers with phone activity in all 12 months, which we also use in the main analysis. Further filters as described in section 4.3. Phone usage statistics include in- and outgoing calls. The *within-degree* measures network size within a radius of 15 minutes around an agent's residence.

B. Appendix: Analysis

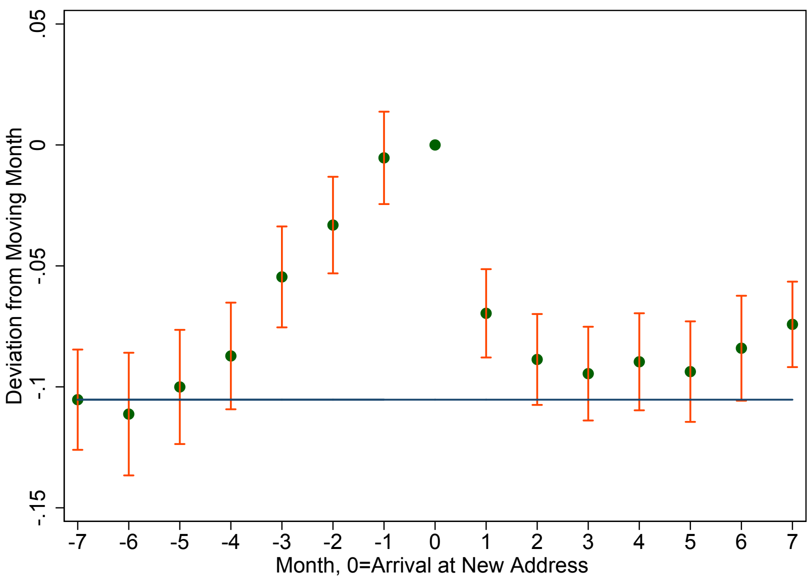


Figure B.1: The Degree prior and after Moving

Robustness Checks: Degree

Table B.1: Robustness – Cities and Network Size, June 2015–May 2016.

		Excluding Months around Change of Residence, i.e. $t = 0$				
Moving Distance at least 30 min.	All Months (0)	$t \neq 0$ (1)	$-2 \leq t \geq 2$ (2)	$-3 \leq t \geq 3$ (3)	$-4 \leq t \geq 4$ (4)	$-5 \leq t \geq 5$ (5)
Hinterland (vs. Cities)	-0.006	-0.007	-0.008	-0.017^{+}	-0.012	-0.015
	(0.006)	(0.006)	(0.007)	(0.009)	(0.012)	(0.020)
Periphery (vs. Cities)	-0.001	0.001	0.002	-0.001	-0.005	-0.027
	(0.007)	(0.007)	(0.009)	(0.011)	(0.015)	(0.024)
R^2	0.011	0.011	0.011	0.010	0.009	0.011
Groups	16,874	16,868	16,808	16,743	16,681	16,535
Observations	185,644	167,761	138,883	113,106	90,018	69,675
Population Density	-0.006	-0.008	-0.011	-0.048^{+}	-0.030	-0.094
	(0.017)	(0.019)	(0.023)	(0.027)	(0.038)	(0.061)
Population Density^2	0.000	0.000	0.000	0.002	0.002	0.005
	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.003)
R^2	0.011	0.011	0.011	0.010	0.009	0.008
Groups	16,874	16,868	16,808	16,743	16,680	16,534
Observations	185,644	167,749	138,872	113,097	90,011	69,670
Further Controls	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes
Language Region FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The *sample* covers movers (minimum moving distance 30min) who used their phone every month at least once. Column (1) excludes the moving month; column (2) excludes the moving month and the first month prior and after moving; and so on. *Further controls* include commuting distance and a dummy for belonging to language minority. Standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

Robustness Checks: Within-Degree

Table B.2: Robustness – Cities and the Within-Degree, June 2015–May 2016.

		Excluding Months around Change of Residence, i.e. $t = 0$				
Moving Distance at least 30 min.	All Months (0)	$t \neq 0$ (1)	-2 $\leq t \geq$ 2 (2)	-3 $\leq t \geq$ 3 (3)	-4 $\leq t \geq$ 4 (4)	-5 $\leq t \geq$ 5 (5)
Hinterland (vs. Cities)	-0.038*	-0.039*	-0.049*	-0.058*	-0.049	-0.084+
	(0.018)	(0.018)	(0.021)	(0.025)	(0.032)	(0.046)
Periphery (vs. Cities)	-0.132***	-0.133***	-0.149***	-0.148***	-0.148***	-0.194***
	(0.020)	(0.021)	(0.024)	(0.028)	(0.036)	(0.053)
R^2	0.012	0.015	0.017	0.016	0.015	0.012
Groups	16,874	16,868	16,808	16,743	16,681	16,535
Observations	185,676	167,761	138,883	113,106	90,018	69,675
Population Density	0.076***	0.077***	0.082***	0.085***	0.087***	0.087***
	(0.006)	(0.006)	(0.007)	(0.008)	(0.010)	(0.015)
R^2	0.016	0.019	0.021	0.020	0.018	0.013
Groups	16,874	16,868	16,808	16,743	16,680	16,534
Observations	185,663	167,749	138,872	113,097	90,011	69,670
Further Controls	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes
Language Region FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The *sample* covers movers (minimum moving distance 30min) who used their phone every month at least once. Column (1) excludes the moving month; column (2) excludes the moving month and the first month prior and after moving; and so on. *Further controls* include commuting distance and a dummy for belonging to language minority. Standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

Robustness Checks: Clustering

Table B.3: Robustness – Cities and Clustering, June 2015–May 2016.

		Excluding Months around Change of Residence, i.e. $t = 0$				
	All Months (0)	$t \neq 0$ (1)	-2 $\leq t \geq$ 2 (2)	-3 $\leq t \geq$ 3 (3)	-4 $\leq t \geq$ 4 (4)	-5 $\leq t \geq$ 5 (5)
Hinterland (vs. Cities)	0.002+	0.002+	0.002	0.004*	0.003	0.002
	(0.001)	(0.001)	(0.001)	(0.002)	(0.003)	(0.004)
Periphery (vs. Cities)	0.002+	0.003*	0.003*	0.006**	0.006*	0.008+
	(0.001)	(0.001)	(0.002)	(0.002)	(0.003)	(0.004)
R^2	0.001	0.001	0.001	0.001	0.001	0.01
Groups	16,870	16,863	16,802	16,735	16,670	16,518
Observations	183,896	166,130	137,489	111,965	89,099	68,953
Population Density	-0.001+	-0.001+	-0.001+	-0.001+	-0.001+	-0.003*
	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)
R^2	0.001	0.001	0.001	0.001	0.001	0.001
Groups	16,870	16,863	16,802	16,735	16,669	16,517
Observations	183,896	166,118	137,478	111,956	89,092	68,948
Further Controls	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes
Language Region FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The *sample* covers movers (minimum moving distance 30min) who used their phone every month at least once. Column (1) excludes the moving month; column (2) excludes the moving month and the first month prior and after moving; and so on. *Further controls* include commuting distance and a dummy for belonging to language minority. Standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

Robustness Checks: Matching

Table B.4: Robustness – Regional Differences in the Matching Quality, Robustness

a. Network Formation	Full Sample		Moving Distance > 30min.	
Cities and Matching (Predicted FE)	(1)	(2)	(3)	(4)
$\text{Hinterland}_{i,t}$	-101.581***		-44.090	
	(-6.316)		(-0.905)	
$\text{Periphery}_{i,t}$	-381.461***		-252.426***	
	(-20.221)		(-4.952)	
Pop. $\text{Density}_{i,t}$		88.509***		56.085***
		(17.412)		(6.019)
Constant	5447.207***	4439.930***	5346.683***	4718.905***
	(414.239)	(88.771)	(121.435)	(54.765)
R^2	0.002	0.001	0.001	0.001
Observations	1,631,708	1,646,566	30,6798	313,072

b. Network Topography	Full Sample		Moving Distance > 30min.	
Cities and Matching (Social Adaption)	(1)	(2)	(3)	(4)
City_{post}	0.308***		0.202***	
	(0.046)		(0.056)	
City_{pre}	-0.231***		-0.275***	
	(0.033)		(0.045)	
Pop. Density_{post}		0.184***		0.099***
		(0.013)		(0.013)
Pop. Density_{pre}		-0.145***		-0.103**
		(0.016)		(0.031)
Constant	0.738***	0.304+	0.754**	0.670***
	(0.124)	(0.176)	(0.282)	(0.033)
R^2	0.017	0.041	0.018	0.005
Further Controls	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes
Language Region FE	Yes	Yes	Yes	Yes
Observations	5,718	5,718	3,108	3,194

Notes: *Dependent Variable in Panel a.:* Predicted dyad specific fixed effect from network formation model outlined in equation (4.10b). *Dependent Variable in Panel b.:* The number of *post-move* contacts at the *post-move* place of residence over the number of *post-move* contacts at the *pre-move* place of residence. *Controls in Panel b.:* Number of contacts at new address prior to moving, commuting distance, dummy for belonging to language minority, and Romansh region), gender and age . Standard errors in parentheses. + p<0.10, * p<0.05, ** p<0.01 *** p<0.001.

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Bern, 15. Januar 2017

Konstantin Büchel